ARMY RESEARCH LABORATORY

A Graphical User Interface (GUI) for Automated Classification of Bradley Fighting Vehicle Shock Absorbers

by Patrick Sincebaugh, William Green,
and Gerard Rinkus

ARL-TR-1621 February 1998

Approved for public release; distribution is unlimited.

Army Research Laboratory
Aberdeen Proving Ground, MD 21005-5069

ARL-TR-1621 **February 1998**

A Graphical User Interface (GUI) for Automated Classification of Bradley Fighting Vehicle Shock Absorbers

Patrick Sincebaugh, William Green
Weapons and Materials Research Directorate, ARL

Gerard Rinkus
Boston University, Boston, MA

Abstract

In this report we describe a diagnostic system that is being utilized to evaluate the condition of armored vehicle shock absorbers. We begin by providing the motivation behind the development of the smart shock absorber test stand (SSATS). We then describe the theory required to evaluate the condition of shock absorbers. This theoretical discussion leads to a description of what real life data are acquired during a shock absorber test, and how it can be analyzed to determine the condition of a shock absorber. We then explain the design and capabilities of the SSATS graphical user interface (GUI), which includes the integration of a neural network classification scheme. We finish by discussing recent results of utilizing the system to test and evaluate Bradley armored vehicle shock absorbers.

Acknowledgments

We would like to thank the U.S. Army Artificial Intelligence Center for continuing to support our development of AI-based systems. We would like to acknowledge Eric Olson and Judy Miller from RRAD for their assistance in providing logistical support and technical assistance pertaining to shock absorber testing. We would also like to thank Dick Suchter, formerly of the Paul Munroe Corporation, for his assistance in providing technical data pertaining to the hydraulic test stand used for this project.

INTENTIONALLY LEFT BLANK.

Table of Contents

INTENTIONALLY LEFT BLANK.

List of Figures

List of Tables

INTENTIONALLY LEFT BLANK.

1. Introduction

The need to develop an improved testing methodology for armored vehicle shock absorbers was identified at the U.S. Red River Army Depot (RRAD). The Combat Vehicle Remanufacturing Facility at RRAD is responsible for the maintenance and overhauling of armored fighting vehicles (AFVs). These vehicles are completely disassembled upon arrival and the individual system components, such as the track and engine block, are diagnostically tested. The vehicles are then reassembled with components that have passed their individual tests. The reassembled vehicles are then performance tested by driving them around a test track for a specified amount of time and distance. If a vehicle meets or exceeds all of the performance criteria, it is released back into the field. There are various functional tests performed on individual system components. However, until the development of the smart shock absorber test stand (SSATS), there was no diagnostic test to evaluate the AFV shock absorbers. The decision to reinstall or discard shock absorbers was based on a nonscientific "touch test" performed after the vehicle was driven around the test track. This testing procedure was not reliable. Failure rates as high as 78% occurred in the field. These high failure rates led to rising expenses and downtime, creating the demand for a significantly better diagnostic testing capability for AFV shock absorbers. The U.S. Army Research Laboratory (ARL) developed and implemented the SSATS to meet this need.

2. Shock Absorber Theory

In order to cause a physical body moving with velocity (v) to come to rest, a deceleration force ($-a$) must be applied. Assuming a constant deceleration, the total distance (S) that is traveled by the body is represented by equation (1),

$$S = v^2/2a, \qquad (1)$$

where v is the initial velocity.

If the velocity that will be reduced to zero is in the vertical direction, then S is equal to the height traveled by the body (H), while the acceleration is equal to the gravitational acceleration (g). This yields equation (2),

$$H = v^2/2g. \tag{2}$$

Solving equations (1) and (2) yields

$$2aS = 2gH. \tag{3}$$

In the case of a shock absorber causing the deceleration of the vertical velocity of an armored vehicle, the deceleration is limited by gravitational forces and is defined as $G = a/g$. Using this value and solving equation (3) for the stopping distance S results in

$$S = H/G. \tag{4}$$

The energy (E) that is stored in a body of weight (W) falling from height (H) is defined by $E = WH$. Substituting the value of H from equation (4) yields,

$$E = GWS, \tag{5}$$

where GW is defined as the active force. For an ideal case, a constant force would result in the constant deceleration of the moving body. Figure 1 displays the force vs. displacement curve representing the ideal case (Harris and Crede 1988). The energy that is dissipated during the deceleration process is defined as the area under the curve of the force vs. displacement diagram.

The theory described previously can be applied to the problem of evaluating the capability of a shock absorber to dissipate energy created by the body of an armored vehicle moving in the vertical direction.

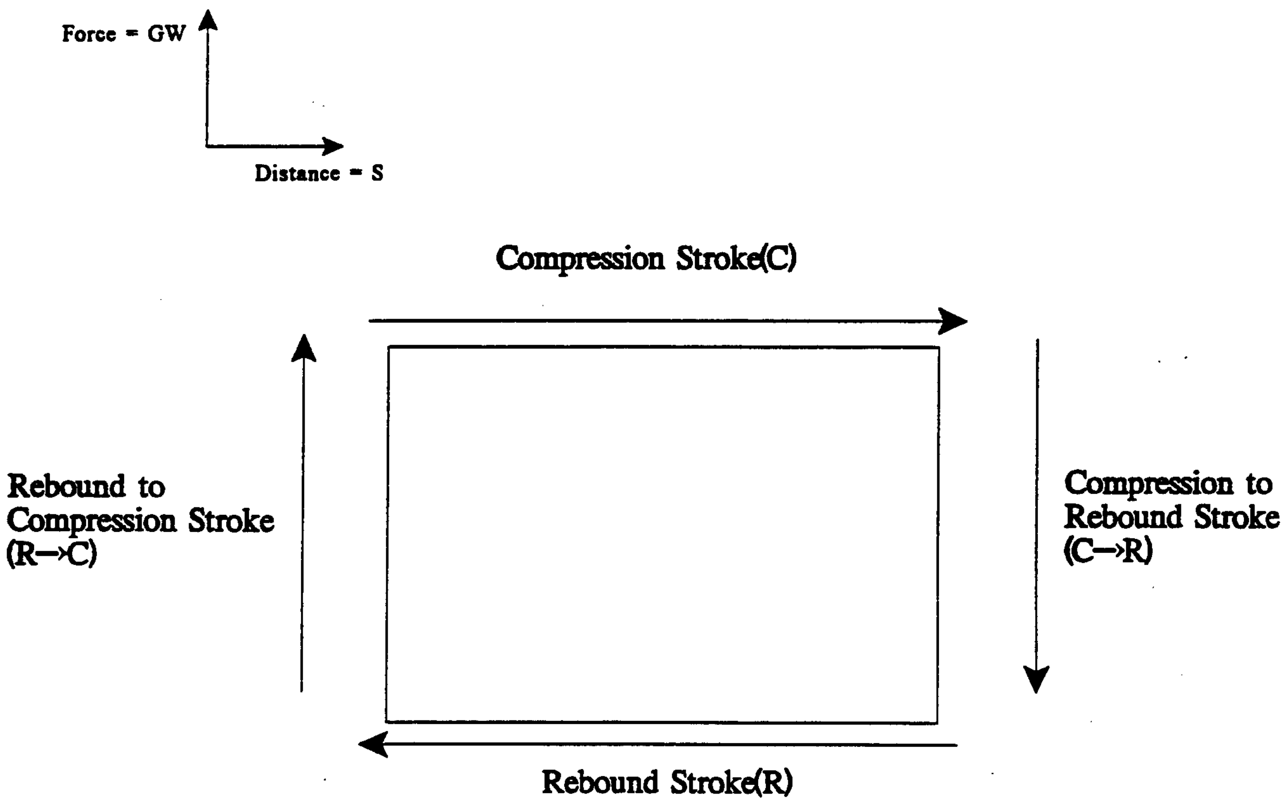


Figure 1. Force vs. Displacement Diagram for an Ideal Shock Absorber.

3. Shock Absorber Test Stand System Development

3.1 Hydraulic Test Stand. A hydraulic test stand was developed to provide a diagnostic testing capability for AFV shock absorbers. The test stand consists of an electronic test console interfaced with a hydraulic power supply. Hydraulic fluid is supplied to a servo cylinder mounted on a load frame. A shock absorber is mounted vertically into the load frame and is subjected to a sinusoidal motion of 38 cycles per minute (CPM) (adjustable up to 290 CPM) at a 2- to 3-in stroke. Sensors are mounted to the test stand and the shock absorber under test in order to acquire data relating to the force on the shock absorber, the resulting displacement, temperature, and the cycle rate.

3.2 Data Acquisition (DAQ) System. A PC-based system was developed to automate the acquisition and analysis of data provided by the hydraulic test stand. Analog voltage signals representing the force applied to the shock absorber, the resulting displacement, the temperature of the shock absorber, and the frequency of oscillation are input to an analog to digital (A/D) converter board plugged into an expansion slot of an 80486 PC. The data signals are connected to the A/D board in a referenced single ended (RSE) configuration. Time is calculated using the sampling rate of the DAQ board, and the average velocity is calculated using the sampling rate and displacement data. The DAQ system was designed to acquire data at five testing frequencies: 38, 50, 100, 150, and 290 CPM. Table 1 depicts the parameters that were used to acquire approximately 100 data points for analysis.

The number of scans/cycle is based upon a DAQ scan rate of 500 Hz and the test frequency. The data bin divisor (DBD) is a number that was calculated to ensure that the number of scans between data points was within the limitations of the A/D conversion rate of the hardware being used. The parameters described previously were coded into the data acquisition software routine to ensure accurate data measurements.

Table 1. Parameters Used to Calculate Number of Data Points

Frequency	No. of Scans/Cycle	DBD	No. of Data Points
38	790	8	99
50	600	6	100
100	300	3	100
150	200	2	100
290	103	1	103

3.3 Data Analysis. A testing procedure for Bradley armored vehicle shock absorbers was developed with the assistance of the shock absorber original equipment manufacturer (OEM) and the quality assurance team at RRAD. The first test requirement specifies a nominal temperature range for the shock absorber being tested. A temperature value is acquired from a thermocouple connected to the shock absorber. The temperature reading is automatically compared by a software analysis routine to determine if it is within the required range. Force values representing the compressive load at midstroke, rebound load at midstroke, load at the first 10% of the compressive stroke, and the load at the first 10% of the rebound stroke are then acquired from load cell sensors. These load values are compared by the software analysis routine to predetermined specified force requirements. If the shock absorber fails the temperature range check, it is tested again at a proper temperature. If the shock absorber fails any portion of the force requirements test and passes the temperature range check, it is considered a faulted shock absorber and is further analyzed by a neural network classification scheme.

Based on the theory described in section 2, it was concluded that the condition of an AFV shock absorber could best be evaluated by analyzing the force vs. displacement diagram of the shock absorber. A testing procedure was developed to collect data as a shock absorber is oscillated at 38 CPM. Preliminary analysis of the data acquired from faulted Bradley armored vehicle shock absorbers shows that the condition can best be classified into four fault categories. These shock absorber fault types are the result of the presence of physical anomalies, such as a bent rod, leaky seal, damaged casing, etc. These categories are named Fault Types 1, 2, 3, and 4. Figure 2 shows

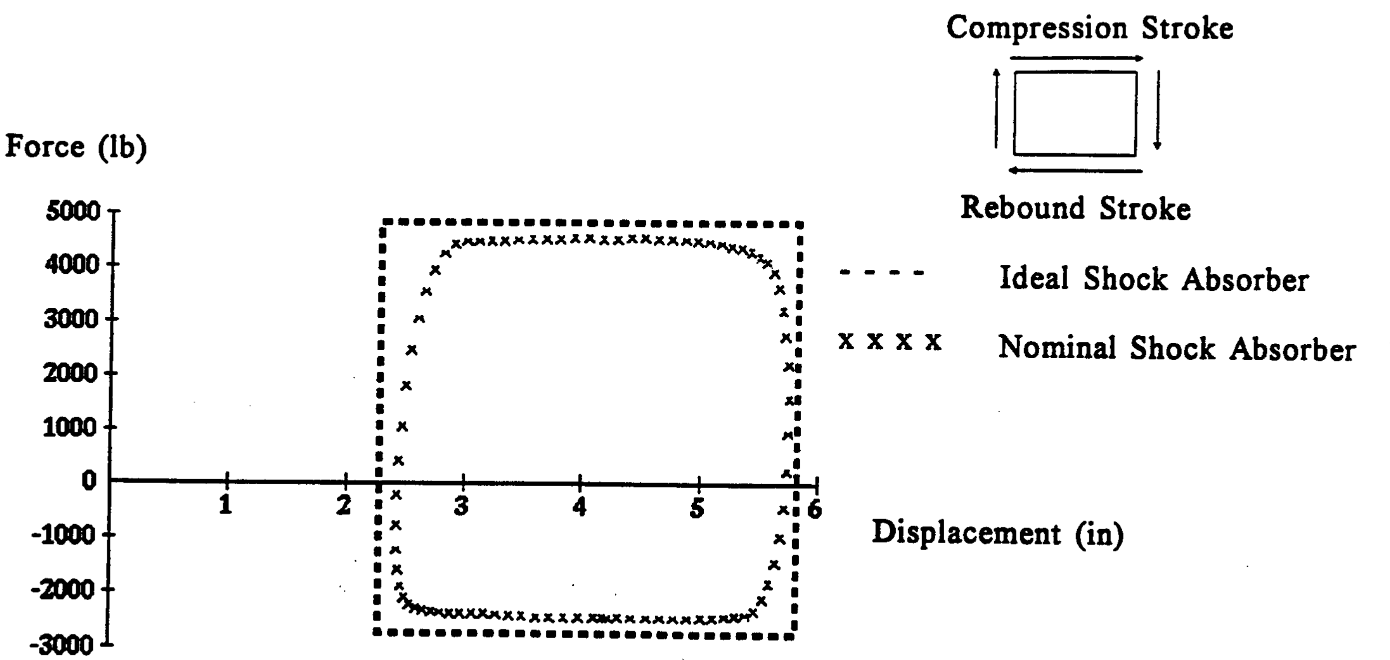


Figure 2. Force vs. Displacement Phase Diagrams for an Ideal and a Nominal BFV Shock Absorber.

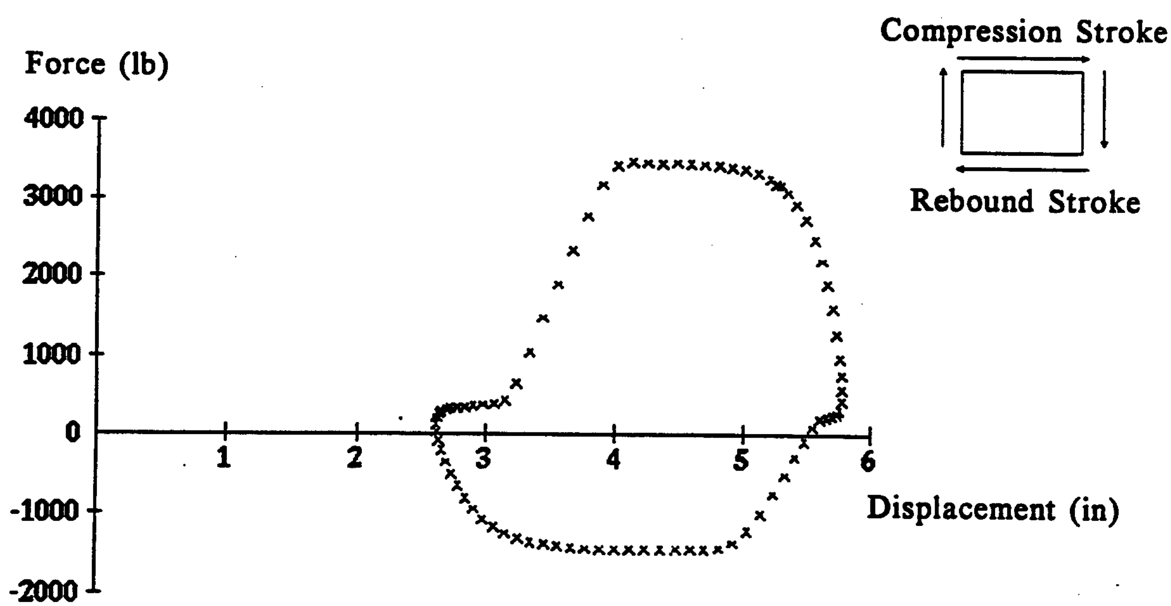


Figure 3. Typical Force vs. Displacement Diagram for a Type 1 Faulted BFV Shock Absorber.

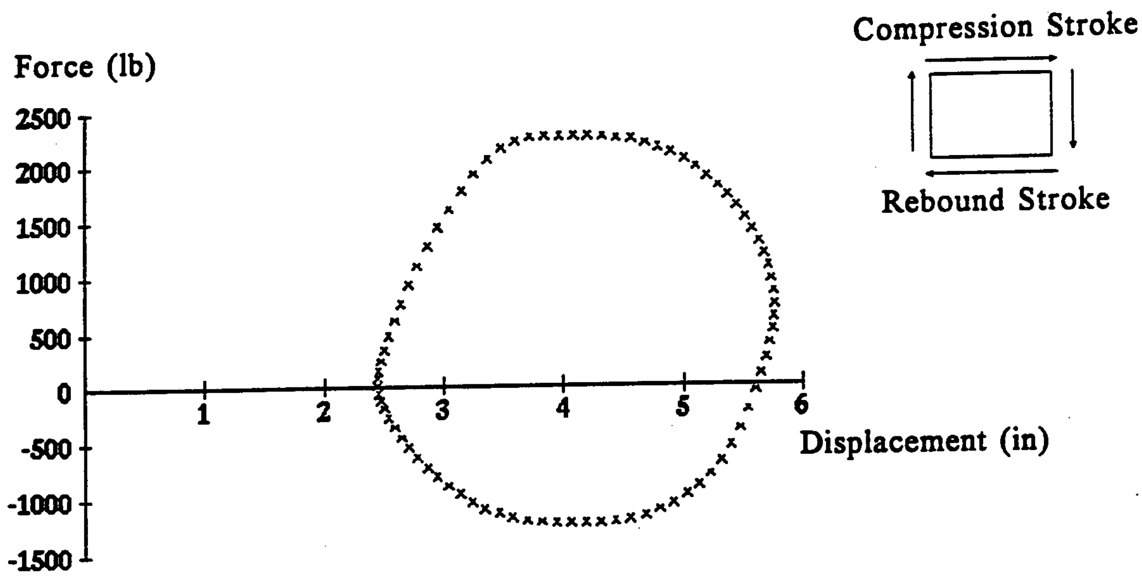


Figure 4. Typical Force vs. Displacement Diagram for a Type 2 Faulted BFV Shock Absorber.

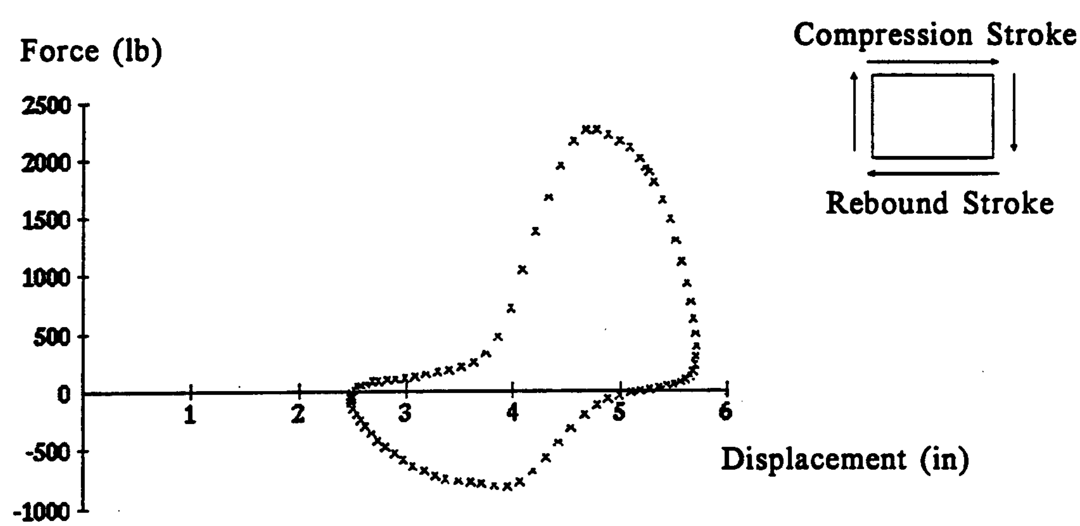


Figure 5. Typical Force vs. Displacement Diagram for a Type 3 Faulted BFV Shock Absorber.

the force vs. displacement diagram for a nominal shock absorber as compared to an ideal shock absorber. Figures 3, 4, and 5 are typical phase diagrams for Fault Types 1, 2, and 3. The Fault Type 4 category was defined to account for unique types of faults and for shock absorbers with a combination of Fault Types 1, 2, or 3.

A fully connected, feed-forward backpropagation neural network was developed to classify the faulted condition of used Bradley armored vehicle shock absorbers. The network architecture consists of an input layer, one hidden layer, and an output layer as shown in Figure 6. The input layer comprises 20 input nodes. The hidden layer comprises eight nodes. The output layer comprises three nodes. Table 2 summarizes the output values and the corresponding fault classifications.

Table 2. Output Nodes Classification

Fault Type	Node 1	Node 2	Node 3
1	>0.85	<0.35	<0.35
2	<0.35	>0.85	<0.35
3	<0.35	<0.35	>0.85

If the network output does not meet any of the criteria outlined in Table 2, then the shock absorber is classified as Fault Type 4. Fault Type 4 can be a unique type of fault for which the network was not trained to recognize, or it could be any combination of Fault Types 1, 2, or 3. There is no corresponding output for a nominal shock absorber since the network is only implemented once the preliminary data analysis determines that the shock absorber is faulted.

A total of 84 Bradley armored vehicle shock absorbers were acquired from RRAD to train the neural network. Eight of the shock absorbers were new and were, therefore, classified as nominal. The condition of the new shock absorbers was verified by analyzing the force vs. displacement plots, temperature values, and load ranges acquired from the hydraulic test stand. The remaining 76 shock

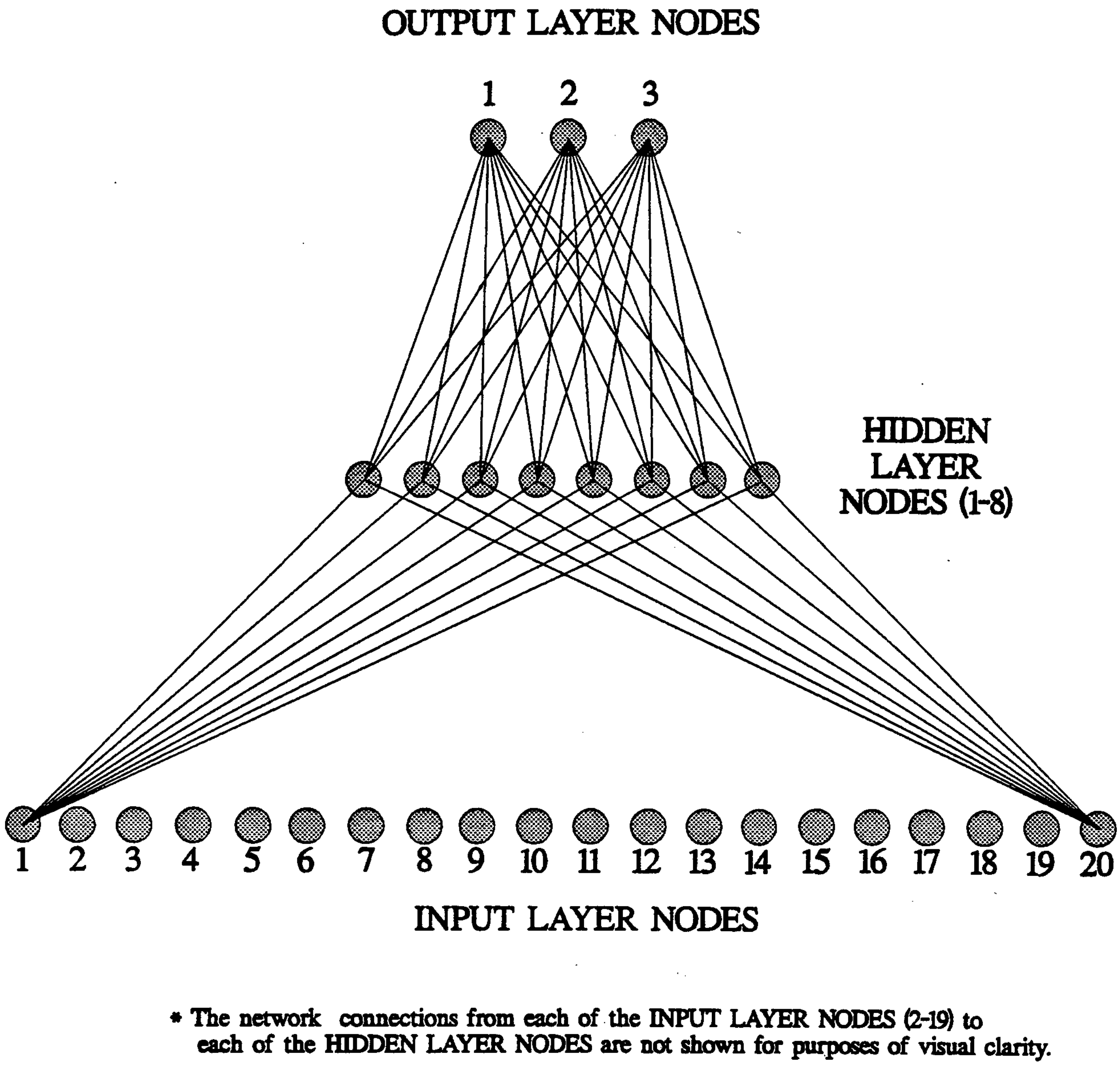


Figure 6. Backpropagation Architecture Used to Classify Faulted BFV Shock Absorbers.

absorbers were faulted. The faulted shock absorbers were categorized as either Fault Types 1, 2, or 3 by analyzing preliminary force vs. displacement plots acquired from the hydraulic test stand. Real data were then acquired and stored for each individual shock absorber. These data were then manipulated into the proper data representation format to train the backpropagation network. After experimenting with the various parameters, such as the learning rate, number of hidden layer nodes, etc., the network was successfully trained to classify the faulted Bradley armored vehicle shock absorbers.

Once the network was adequately trained, it was tested using shock absorbers of known condition. The network successfully classified 100% of the shock absorbers. The neural network was then converted to C code and integrated with the previously written testing software. This completed the development of the SSATS GUI.

4. The SSATS GUI

The SSATS graphical interface is a software application that controls the acquisition, display, and analysis of shock absorber testing data in near real time. It also easily performs statistical process control (SPC) for product assurance and can retrieve for display archival data files. Figure 7 shows the hierarchical relationship between the windows that make up the interface. Appendix A shows each of these windows. Each window also has items that control processes in that window or access to other windows, including one or some combination of buttons, pull-down menus, variable numeric inputs, or scroll bars. Each window also has items that provide necessary information to the user, which include one or some combination of simple numeric and text indicators, green/red LED style indicators, histograms, or plots.

The main window at the top of the hierarchy provides access to the following:

- Shock absorber testing window (SATW): Used to test and classify shock absorbers.

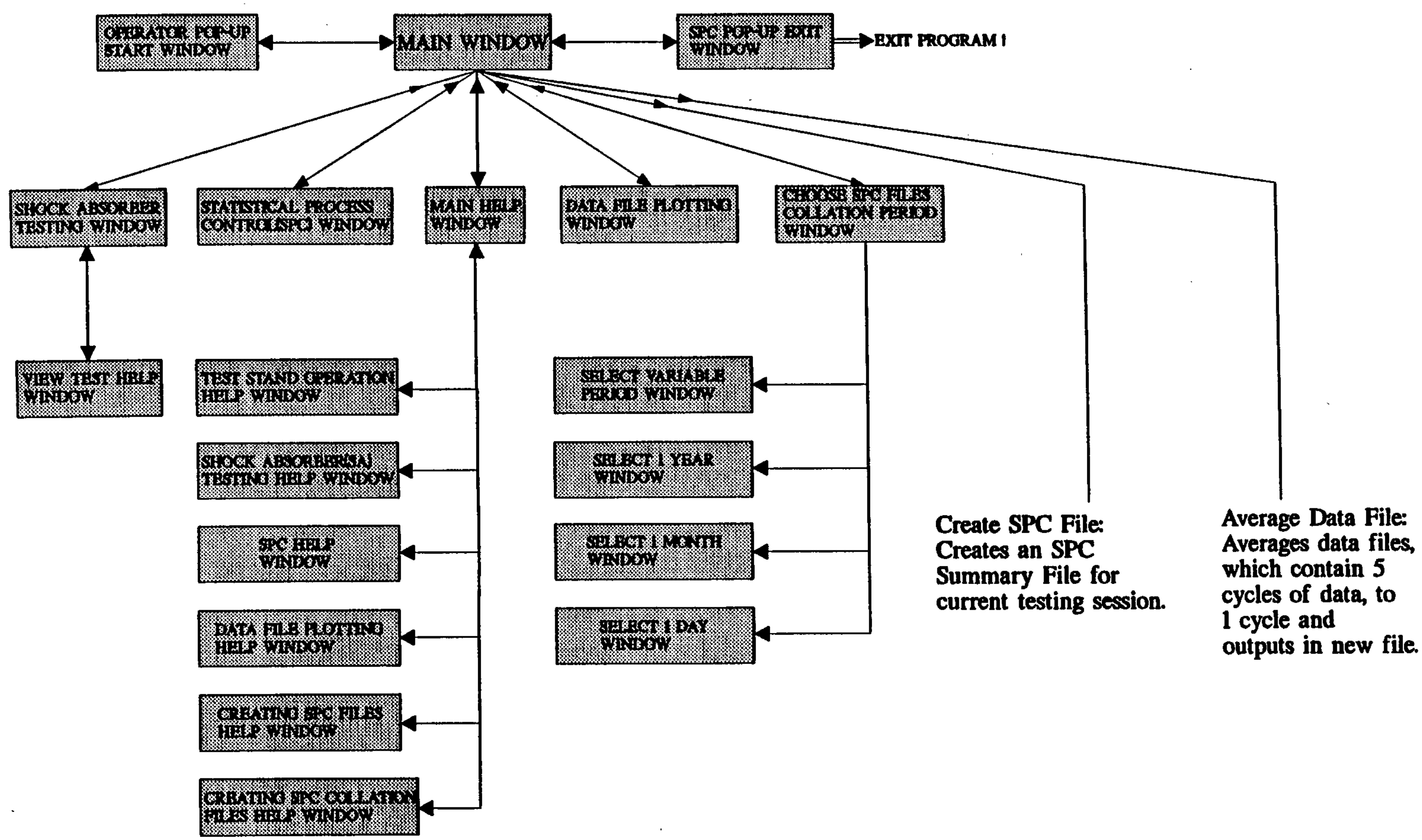


Figure 7. SSATS Interface Windows Hierarchy.

• SPC window (SPCW): Used to graphically view the statistical breakdown of classification data in the current testing session.

• Main help window (MHW): Used to read on-line information concerning all aspects of testing shock absorbers and using the graphical interface itself.

• Data file plotting window (DFPW): Used to retrieve and plot existing data files.

• Choose SPC files collation period window (CSFCPW): Used to summarize data from one or more SPC summary files into a single SPC collation file which inclusively covers the user -defined time period.

An SPC summary file can be created from the main window using the "create SPC file" button. These files contain the statistical breakdown of classification data in the current testing session. Figure 8 is an example of an SPC summary file, and Figure 9 is an example of an SPC collation file. Test data files always contain just over 5 cycles of data regardless of the testing frequency. Average test data files can be also created from the main window, in which 5 cycles are evenly weighted and averaged.

The SATW displays the load (L) vs. position (x) phase diagram, the load history plot, and the temperature history plot of the shock absorber under test while the test is in progress. The SATW also displays one cycle at a time and replaces it with the following cycle over the course of 5 cycles. The user individually sets the "save data" and "retest" buttons to yes or no, and makes a selection from the "number cycles of data" pull-down menu before beginning a test. The selection from the pull-down menu must accurately reflect the actual testing frequency. The retest capability is used to test the same shock absorber again, such as when the first test is done at an improper temperature. The "state of testing" indicator informs the user that a test is in progress.

Acquisition and display of test data begin immediately after the "start test" button is set to "on." The shock absorber under test must be oscillating in the load frame of the test stand before data acquisition begins. After data acquisition for all cycles is complete and the data fully analyzed, which may require neural network classification, the "test result" indicator displays nominal, faulted-types 1, 2, 3, and 4, temperature failure—retest at 38 CPM or unknown—retest at 38 CPM.

BRADLEY SHOCK ABSORBER TESTING SPC SUMMARY: Fri, Feb 17, 1995 - #1
FILENAME: c:\braddata\02175sc1.s38

Shock Absorbers Tested: 20
Nominal Shock Absorbers: 15
Percentage (%) Nominal Shock Absorbers: 75.0
Faulted Shock Absorbers: 5
Percentage (%) Faulted Shock Absorbers: 25.0

Faulted Shock Absorbers - Type 1: 3
Percentage (%) Faulted - Type 1: 15.0
Faulted Shock Absorbers - Type 2: 1
Percentage (%) Faulted - Type 2: 5.0
Faulted Shock Absorbers - Type 3: 1
Percentage (%) Faulted - Type 3: 5.0
Faulted Shock Absorbers - Type 4: 0
Percentage (%) Faulted - Type 4: 0.0

Figure 8. SPC Summary File.

SPC Collation File - all SPC data in 0295 collated.
FILENAME: c:\braddata\025monsc.c38

Shock Absorbers Tested: 80
Nominal Shock Absorbers: 35
Percentage (%) Nominal Shock Absorbers: 43.8
Faulted Shock Absorbers: 45
Percentage (%) Faulted Shock Absorbers: 56.2

Faulted Shock Absorbers - Type 1: 3
Percentage (%) Faulted - Type 1: 3.8
Faulted Shock Absorbers - Type 2: 11
Percentage (%) Faulted - Type 2: 13.8
Faulted Shock Absorbers - Type 3: 21
Percentage (%) Faulted - Type 3: 26.2
Faulted Shock Absorbers - Type 4: 10
Percentage (%) Faulted - Type 4: 12.5

Figure 9. SPC Collation File for Any Single Month.

"Temperature failure" indicates that testing was done at an improper temperature. "Unknown" indicates that testing was not done at a frequency of 38 CPM. Since the neural network was trained on data taken at 38 CPM, shock absorbers tested at other frequencies will not be classified. This requires another test at 38 CPM. However, data can still be acquired and stored at other frequencies. The SATW also individually shows if the testing temperature was within the proper range, if the shock absorber met the load requirements, and if the shock absorber should be rejected with the "temperature test failure," "load test failure," and the "reject shock LED" style indicators, respectively. The "view test help" button provides on-line help on usage of the SATW. The "exit test window" button returns the user to the main window.

The SPCW displays, numerically and graphically, the number of nominal and faulted shock absorbers and the number of each type of faulted shock absorber classified in the current testing session. This statistical description is updated each time a shock absorber is classified. This information is given in the SPC data listing and the "# nominal and # faulted shock absorbers" and "# Faulted Shock Absorbers - Types 1, 2, 3, 4" histograms. The SPCW can be accessed any time a test is not in progress.

The MHW displays several buttons which allow the user to view on-line help information on any one of six different topics, including operation of the test stand, testing procedure, SPC, plotting archived data files, creating SPC files, and collating SPC files. The MHW can be accessed any time a test is not in progress.

The DFPW displays two user-defined plots. Each plot is defined by making a selection from the pull-down menu above it, which includes L vs. x, L vs. v (velocity), v vs. x, L vs. t (time), and x vs. t. The user can interchange the x and y axis of either plot. Selection of the existing data file from which to generate the plots begins immediately after the "plot data file" button is set to "on." The DFPW can be accessed any time a test is not in progress.

The CSFCPW displays a pull-down menu, SPC file collation period, from which to select the time period over which SPC summary files will be collated. The choices include any day, any month, any year, or a variable period. In each case, the time period is then exactly defined by the user. In the case of a 1-yr collation, SPC collation files for each month of that year are further collated to minimize the number of files involved. The CSFCPW can also be accessed any time a test is not in progress.

5. BFV Shock Absorber Test Results

The SSATS system tested and evaluated 57 BFV shock absorbers at RRAD over the period 7 August 1996 to 18 September 1996. Table 3 gives the load specifications, where ML(C), ML(R), DL(C), and DL(R) are the mid-stroke load in compression, mid-stroke load in rebound, damping load in compression, and damping load in rebound, respectively. Each damping load is defined to be the load after completing 10% of the stroke. The specifications were determined with the assistance of the shock absorber OEM and the quality assurance team at RRAD.

Table 3. Load Specifications

Type	Requirement
ML(C)	ML(C) > or = 2,310.0 lb ML(C) < or = 4,760.0 lb
ML(R)	ML(R) > or = 1,680.0 lb ML(R) < or = 2,310.0 lb
DL(C)	DL(C) > or = 1,155.0 lb
DL(R)	DL(R) > or = 840.0 lb

Figure 10 shows how the load (force) vs. position (displacement)-phase diagram of a shock absorber is divided into the compression stroke and rebound stroke. It also shows the location of ML(C) and ML(R). The average values of ML(C), ML(R), DL(C), and DL(R) were determined for each shock absorber and are listed in Appendix B. Names of data files in Appendix B are in "mmddyBn" format, in which "mm" denotes a two-digit month, "dd" denotes a 2-digit day, "y" denotes the last

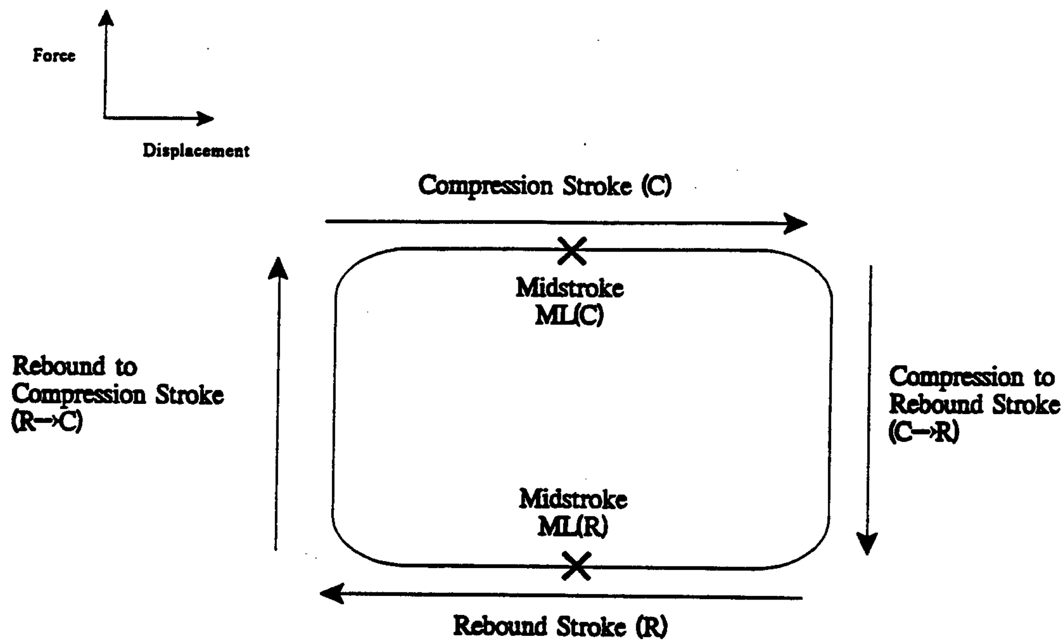


Figure 10. Midstroke Position of Compression Stroke.

digit of a year, and "n" denotes a shock absorber test number. In this way, each shock absorber test is uniquely identified by day, month, year, and test number, which changes over the course of a day.

Only data from 55 of the 57 data files listed in Appendix B were considered, since the data for test nos. 09166B3 and 09176B2 were taken at a temperature out of the proper testing range. Using the load specifications given in Table 3, 12 out of the 55 shock absorbers, approximately 22%, were found to be nominal. The average values of ML(C), ML(R), DL(C), and DL(R) for nominal shock absorbers were 4,113.44 lb, 1,773.96 lb, 2,793.25 lb, and 1,324.65 lb, respectively. Most of the 43 faulted shock absorbers could be categorized as either failing one load requirement, which was always ML(R), or two or more load requirements, which usually included ML(R) and DL(R). This is shown in Appendix C. The average values of ML(C), ML(R), DL(C), and DL(R) for faulted shock absorbers that only failed ML(R) were 3,856.21 lb, 1,624.28 lb, 2,559.08 lb, and 1,091.66 lb, respectively. The average value of ML(R) in these cases is within approximately 3% of the specification. Decreasing the lower limit of the ML(R) specification by 5% (to 1,596 lb) would result in 37 nominal shock absorbers and 18 faulted shock absorbers, an increase of nominal shock absorbers of approximately 45%. The average values of ML(C), ML(R), DL(C), and DL(R) for faulted shock absorbers that failed ML(R) and DL(R) were 3,314.35 lb, 1,397.70 lb, 1,889.95 lb, and 630.45 lb, respectively. The average values of ML(R) and DL(R) for these shock absorbers are significantly less than the values for shock absorbers only failing ML(R).

Figure 11 shows the load vs. position phase diagram for nominal shock absorber no. 08236B5. Figure 12 shows the load vs. position phase diagram for faulted shock absorber no. 08236B7, which only failed the ML(R) requirement. This shock absorber was classified as Faulted, Type 1. The phase diagrams of shock absorber nos. 08236B5 and 08236B7 have very similar shapes. Figure 13 shows the load vs. position phase diagram for shock absorber no. 09126B6, which failed ML(R) and DL(R) requirements. This shock absorber was classified as Faulted, Type 2. The phase diagram of no. 09126B6 is shaped similar to an oval. The phase diagrams for shock absorber nos. 08236B7 and 09126B6 are dissimilar. Figure 14 shows the load vs. position phase diagram for faulted shock absorber no. 09126B3, the single faulted shock absorber that only failed ML(R) and DL(C) requirements. This shock absorber was classified as Faulted, Type 1. Figure 15 shows the load vs. position phase diagram for faulted shock absorber no. 08076B3, which failed each requirement. This shock absorber was classified as Faulted, Type 2. Figure 16 shows the load vs. position phase diagram for the Type 4 shock absorber no. 08216B2. This shock absorber was similar enough to both Type 1 and Type 2 that it was not classified as either. The number of faulted shock absorbers classified as Type 1, Type 2, and Type 4 were 28, 12, and 3, respectively. No faulted shock absorbers were classified as Type 3. The classification of each faulted shock absorber is given in Appendix D.

6. Conclusions

The Materials Directorate* (MD), ARL, has developed and implemented a SSATS based on an interactive GUI to evaluate the condition of armored vehicle shock absorbers. The GUI is a software

* Materials Directorate was transitioned to Materials Division within the Weapons & Materials Technology Directorate (WMRD).

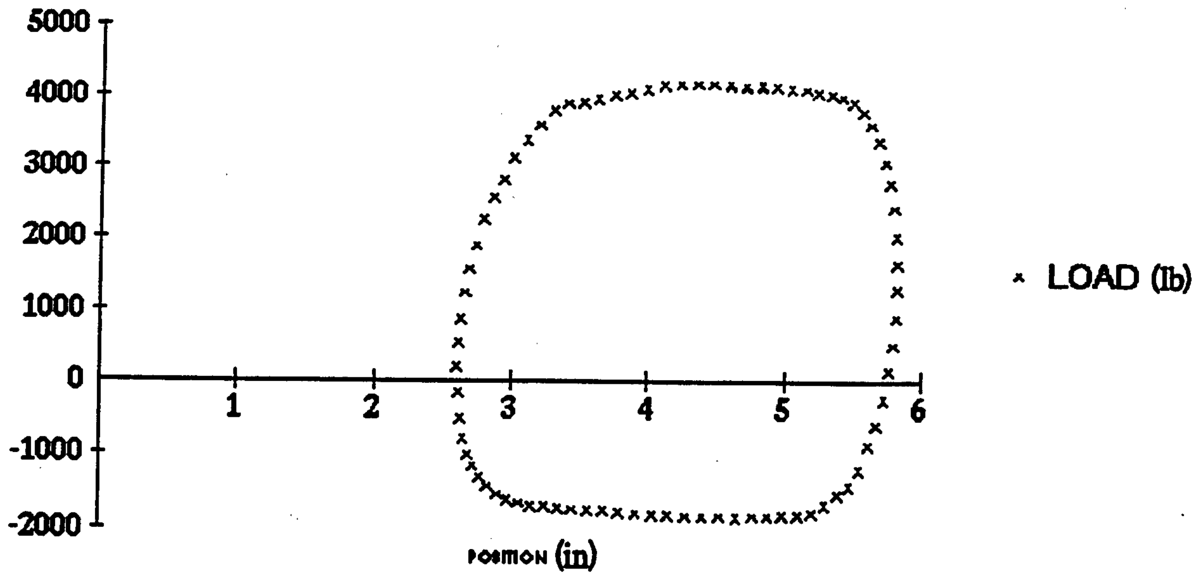


Figure 11. Load vs. Position Phase Diagram for Nominal Shock Absorber No. 08236B5.38.

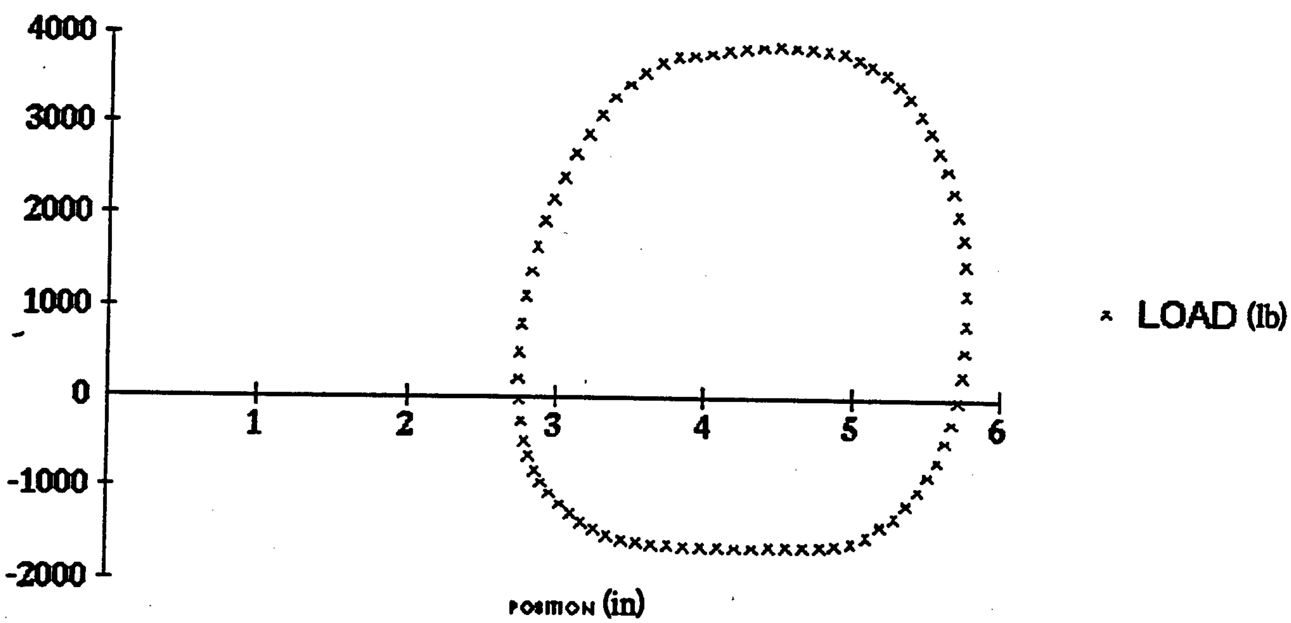


Figure 12. Load vs. Position Phase Diagram for Faulted Shock Absorber No. 08236B7.38.

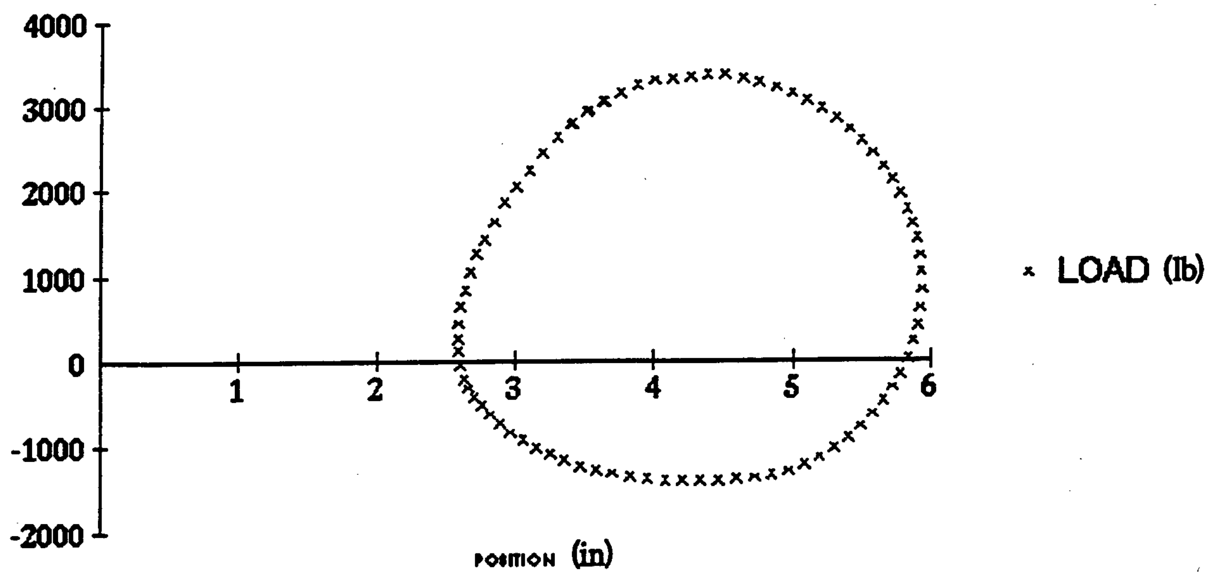


Figure 13. Load vs. Position Phase Diagram for Faulted Shock Absorber No. 09126B6.38.

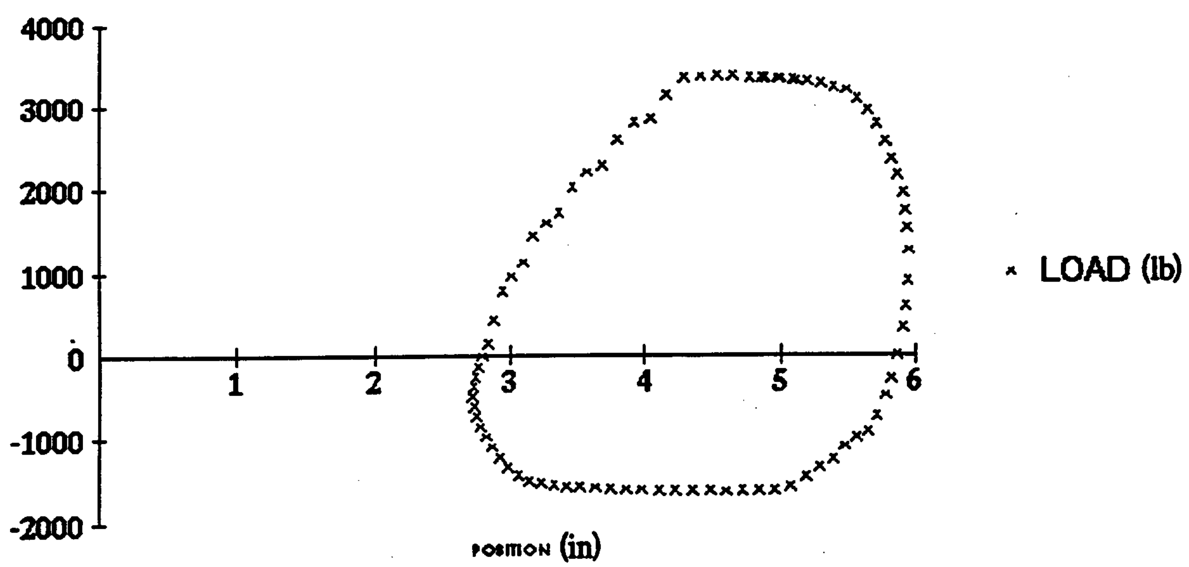


Figure 14. Load vs. Position Phase Diagram for Faulted Shock Absorber No. 09126B3.38.

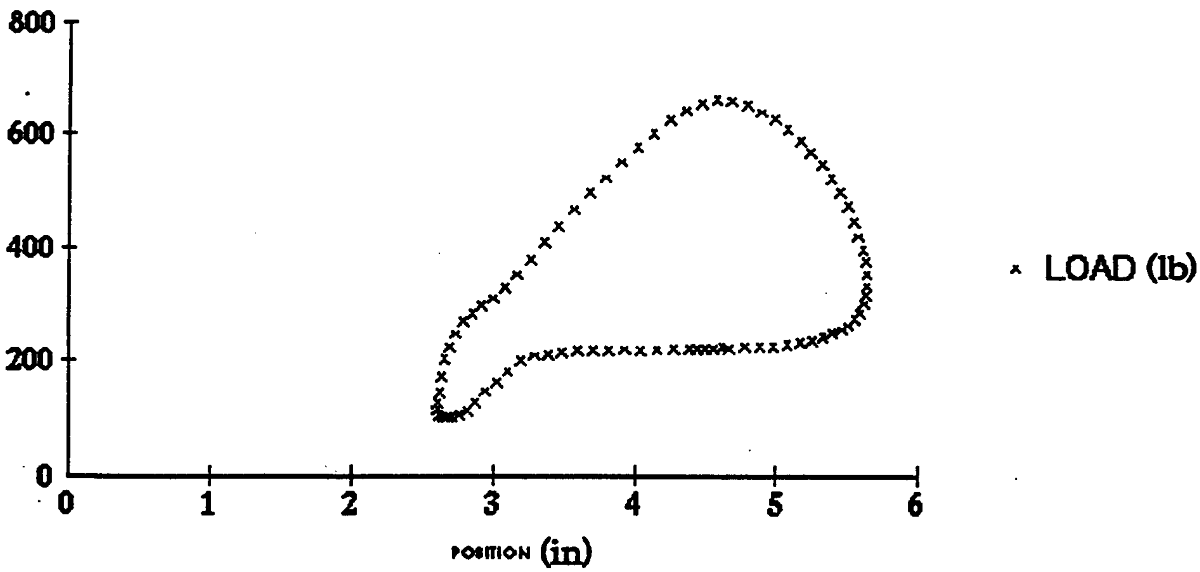


Figure 15. Load vs. Position Phase Diagram for Faulted Shock Absorber No. 08076B3.38.

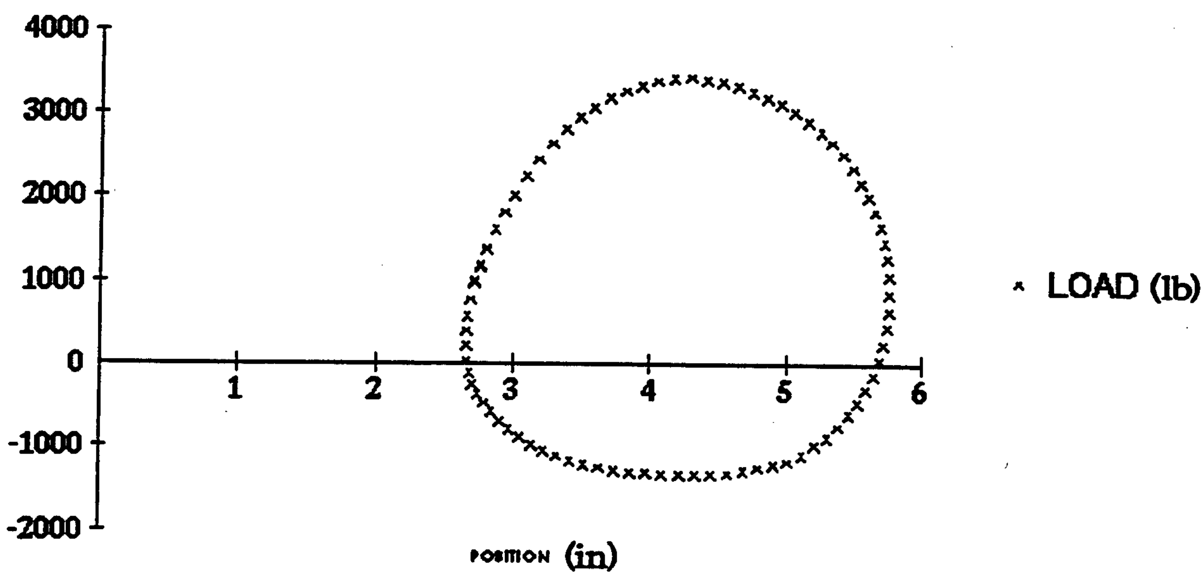


Figure 16. Load vs. Position Phase Diagram for Faulted Shock Absorber No. 08216B2.38.

application that controls acquisition, display, and analysis of testing data, performs SPC for product assurance, and plots archived data files. The shock absorber is mounted in a hydraulic test stand which oscillates the shock at a preset frequency. A DAQ system acquires data from sensors mounted to the test stand and the shock absorber. These data are analyzed in order to classify the shock absorber as nominal or faulted. If the shock absorber is classified as faulted, the data are further analyzed by a neural network based classification scheme. A fully connected feed-forward backpropagation network was successfully trained and tested to classify the faulted shock absorbers as either Fault Type 1, Fault Type 2, Fault Type 3, or Fault Type 4. These shock absorber fault characteristics are present due to physical anomalies, such as a bent rod, leaky seal, damaged casing, etc. Classifying the fault types and archiving the results enables the user to track the problems associated with the shock absorbers and to monitor any significant trends. For example, a high percentage of shock absorbers with leaky seals may represent a design problem which can be corrected by the manufacturer.

Once developed and tested, the SSATS system was transitioned to RRAD where it is being utilized to evaluate the condition of Bradley armored vehicle shock absorbers. The system was first implemented to evaluate shock absorbers that had been previously tested at RRAD by visual inspection and by a nonscientific "touch test." It was discovered that this nondiagnostic testing technique resulted in the misclassification of 40% of the shock absorbers.

The SSATS system tested and evaluated 57 shock absorbers at RRAD in August and September 1996. It was determined that 12 out of the 55 shock absorbers, approximately 22%, were nominal. It was also determined that 33 out of the 55 shock absorbers, or 60%, only failed the ML(R) load requirement. The shape of the load vs. position phase diagrams for these shock absorbers was very similar to the shape of the phase diagrams for nominal shock absorbers. In contrast, the shape of the phase diagrams for other faulted shock absorbers was dissimilar to those of nominal shock absorbers. The ML(R) specification could be considered for modification at this time. However, the ML(R) specification should remain significantly above the average ML(R) for shock absorbers that failed both ML(R) and DL(R). If the ML(R) requirement is decreased too drastically, this could result in poor shock absorbers being accepted for reuse.

The SSATS system provides an accurate functional testing capability for armored vehicle shock absorbers by implementing a neural network based classification scheme. The utilization of this system reduces vehicle downtime, resulting in an increase in combat readiness and a significant financial savings.

7. References

Harris, C. M., and C. E. Crede. *Shock and Vibration Control Handbook*, 3d ed., p. 395, 1988.

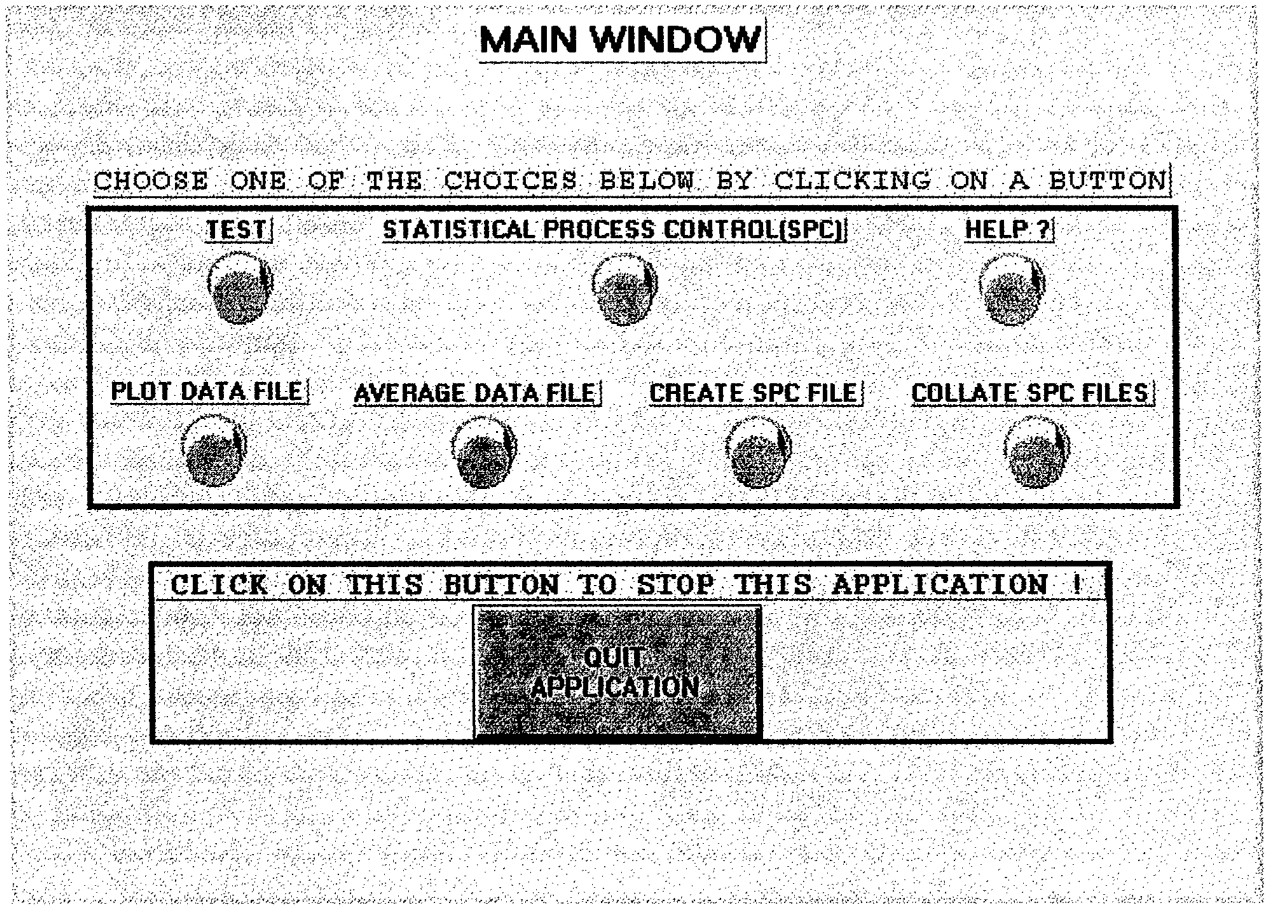
INTENTIONALLY LEFT BLANK.

Appendix A:

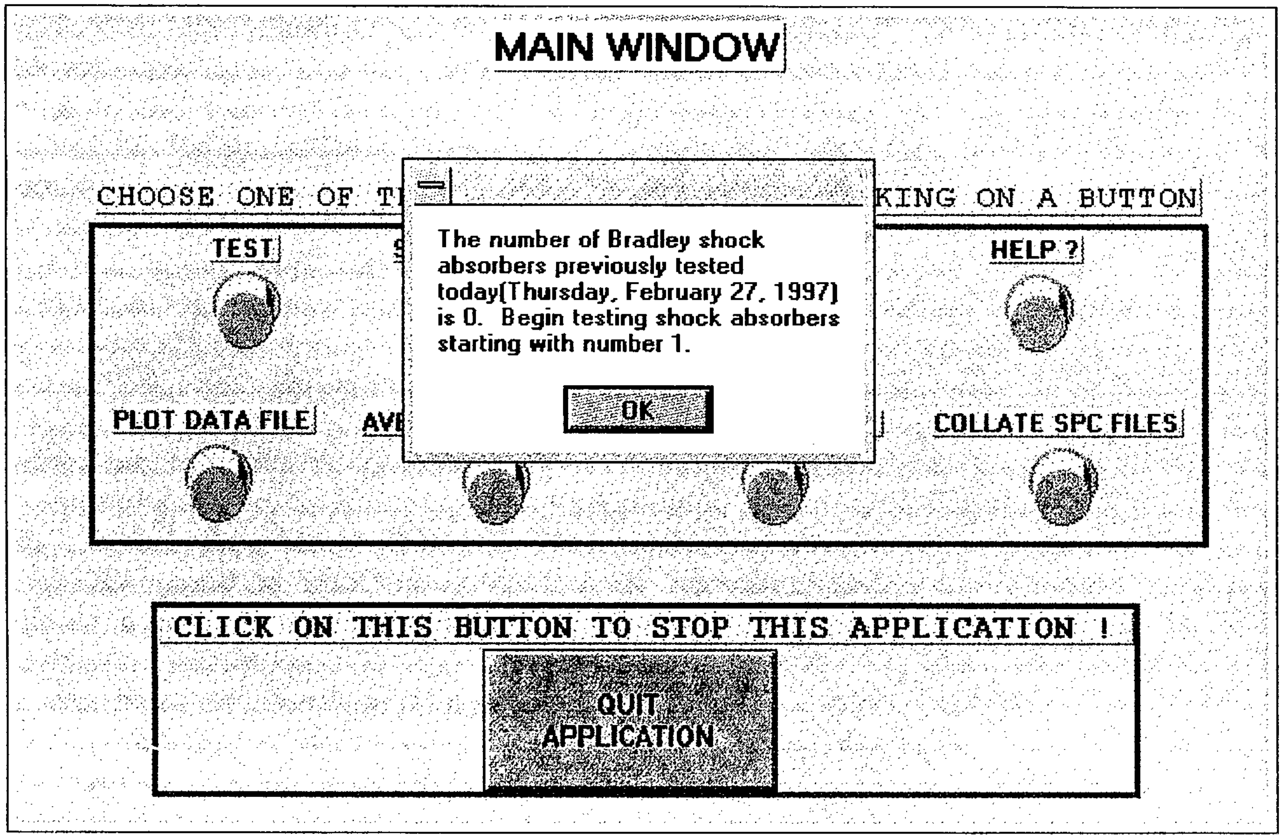
SSATS GUI Windows

INTENTIONALLY LEFT BLANK.

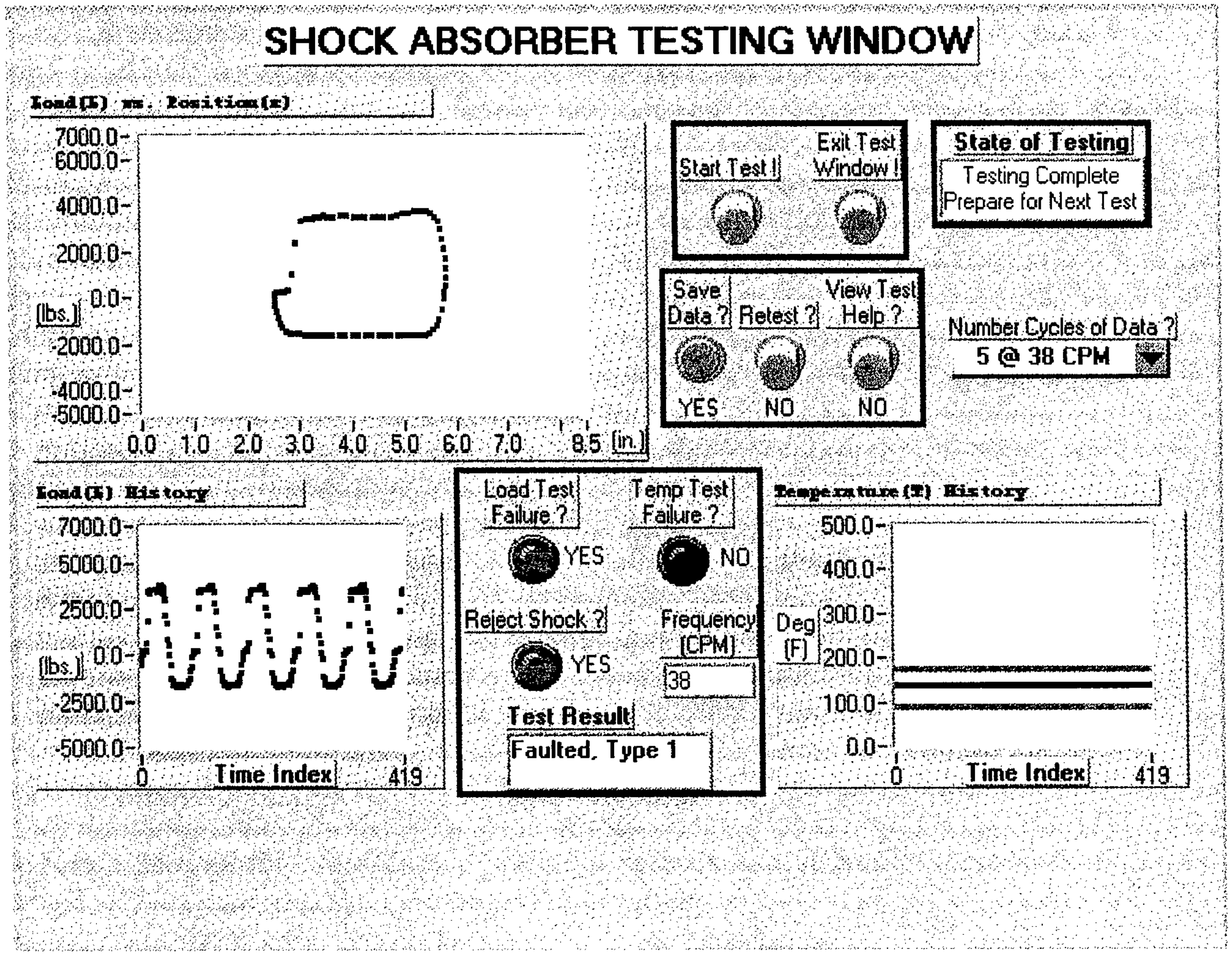
THE MAIN WINDOW



THE OPERATOR POP-UP START WINDOW



THE SHOCK ABSORBER TESTING WINDOW



THE VIEW TEST HELP WINDOW

VIEW TEST HELP WINDOW

HOW TO USE THE SHOCK ABSORBER TESTING WINDOW:

Step 1 - Set the Save Data ? button by clicking on it with the left mouse button. The text below the Save Data ? button will indicate if data is or is not being saved.

Step 2 - Set the Number Cycles of Data ? menu by first pressing and holding down the left mouse button after placing the mouse cursor over the downward pointing black triangle to the right of the menu. Then, while holding down the left mouse button, move the cursor such that it highlights a single menu choice. Let go of the mouse button.

Step 3 - Set the Retest ? button by clicking on it with the left mouse button. Set it to NO if a new shock absorber is being tested; set it to YES if the same shock absorber is being retested.

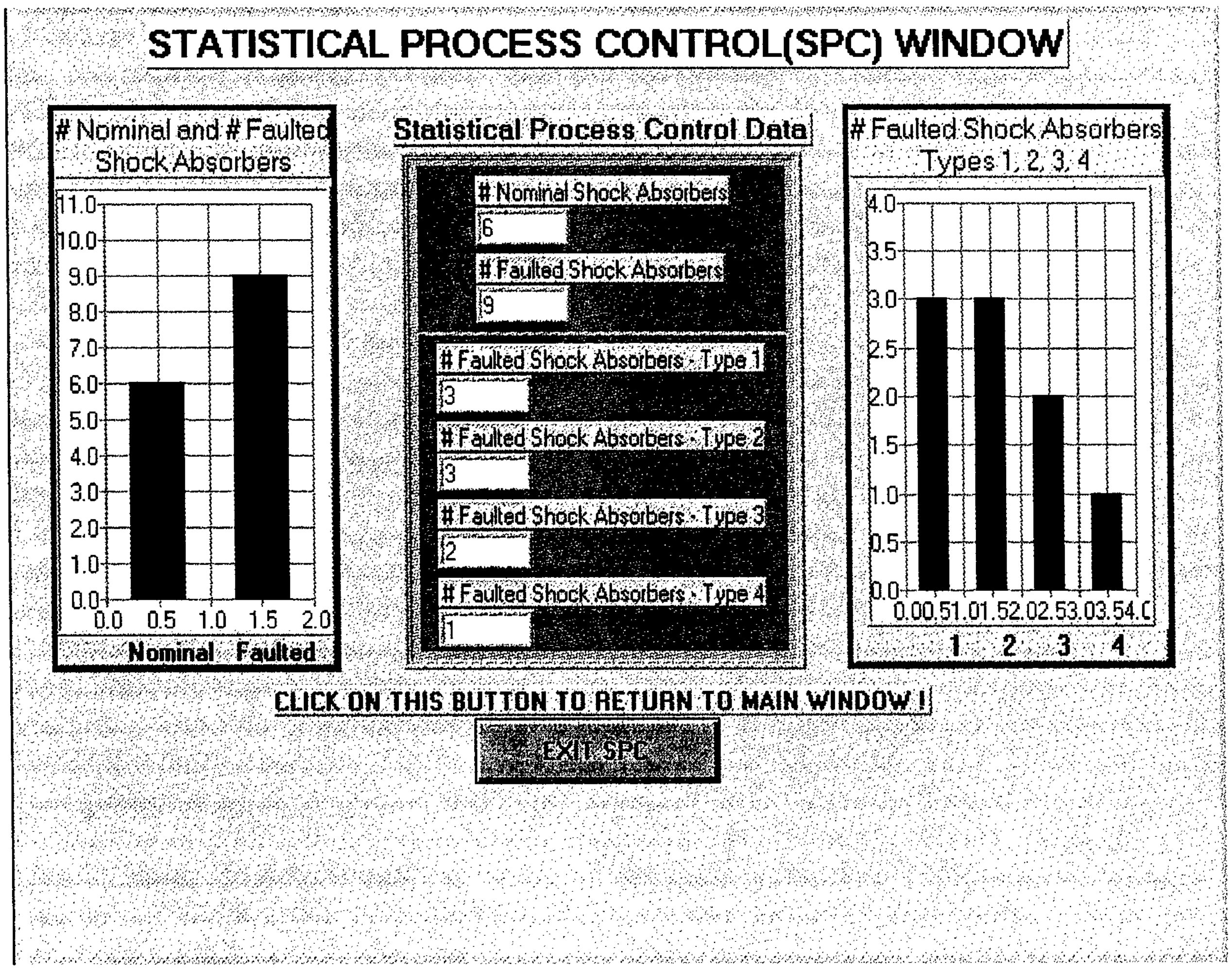
Step 4 - Click on the Start Test ! button to begin the acquisition of data. The acquisition will stop itself.

Step 5 - Click on the Exit Test Window ! button to exit the SHOCK ABSORBER TESTING WINDOW and return to the MAIN WINDOW.

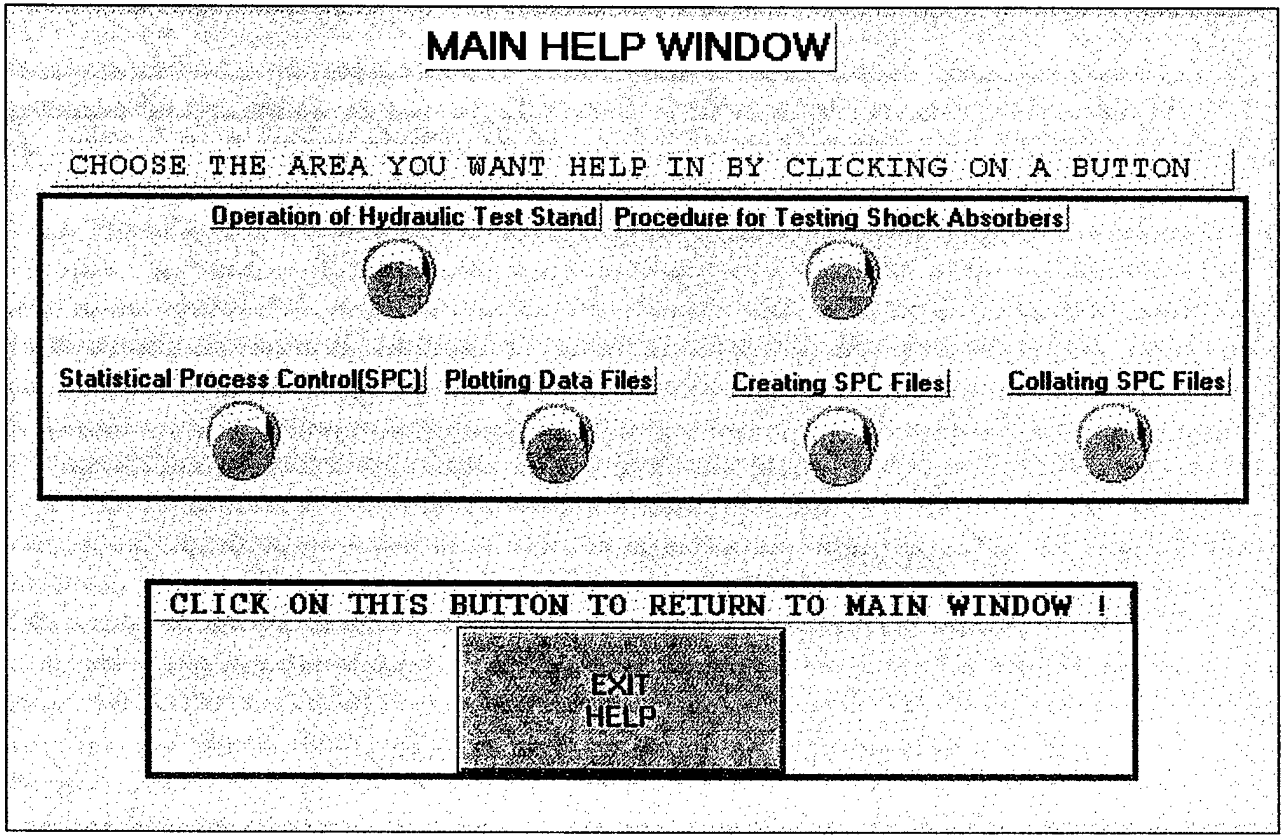
CLICK ON THE BUTTON BELOW TO RETURN TO THE SHOCK ABSORBER TESTING WINDOW !

EXIT THIS WINDOW

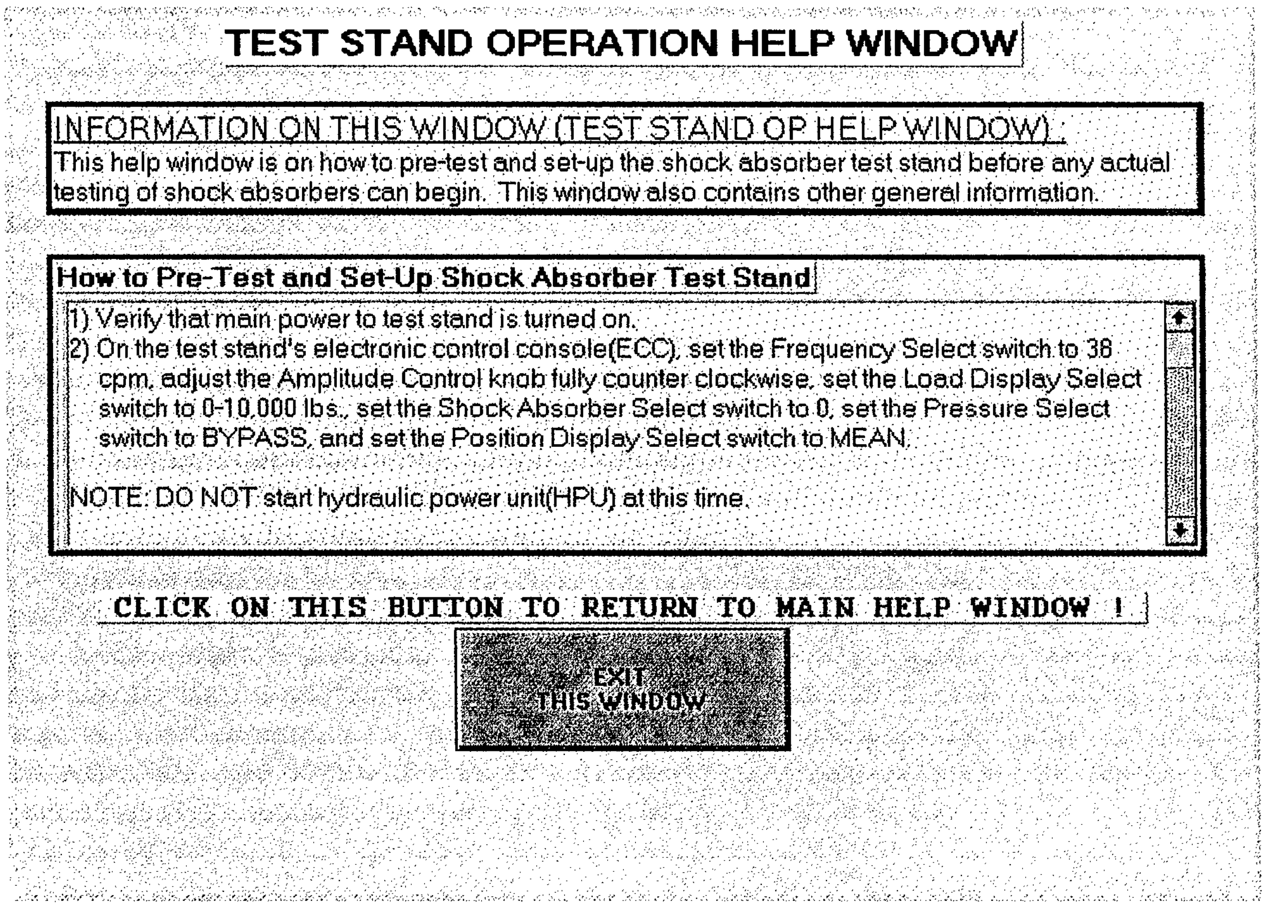
THE STATISTICAL PROCESS CONTROL(SPC) WINDOW



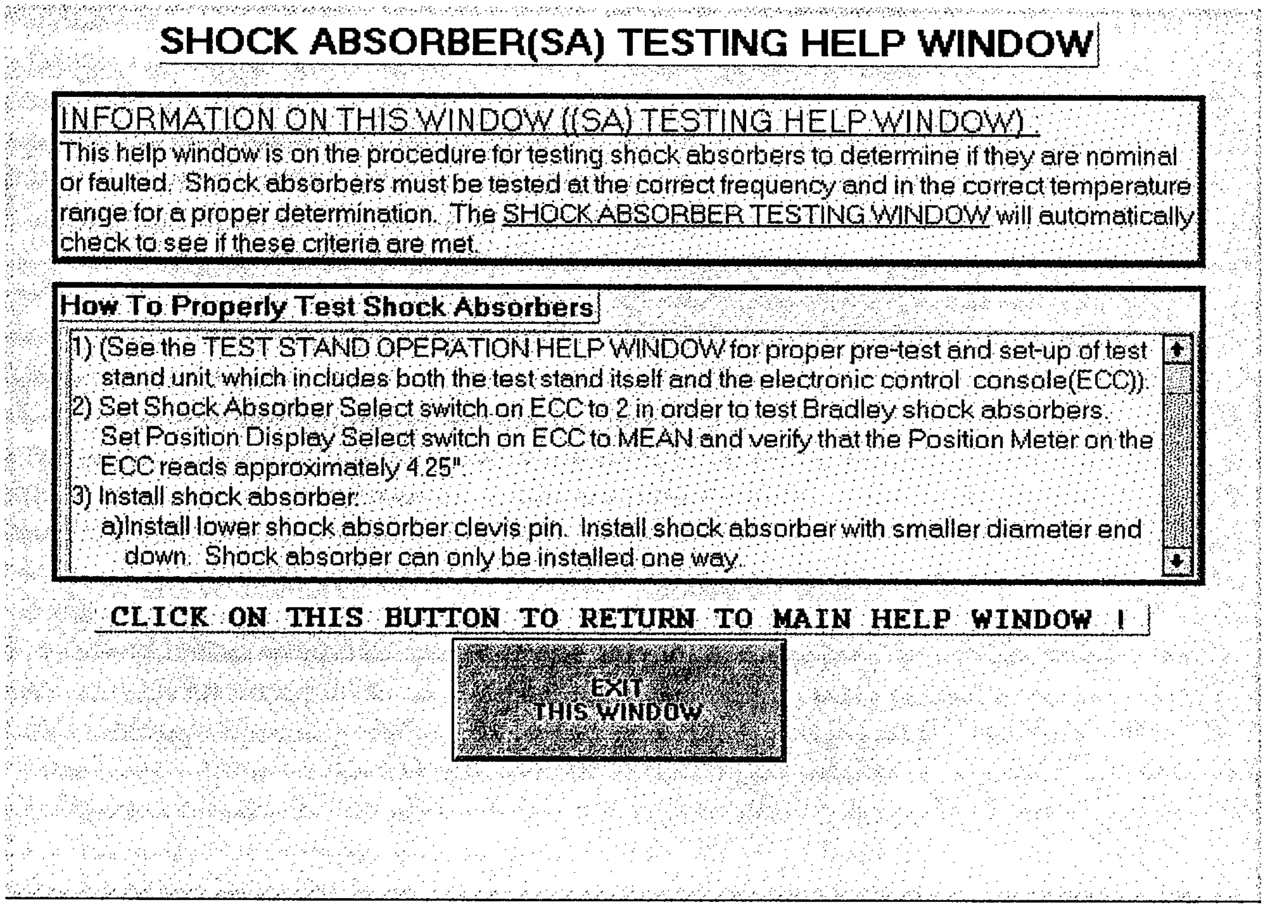
THE MAIN HELP WINDOW



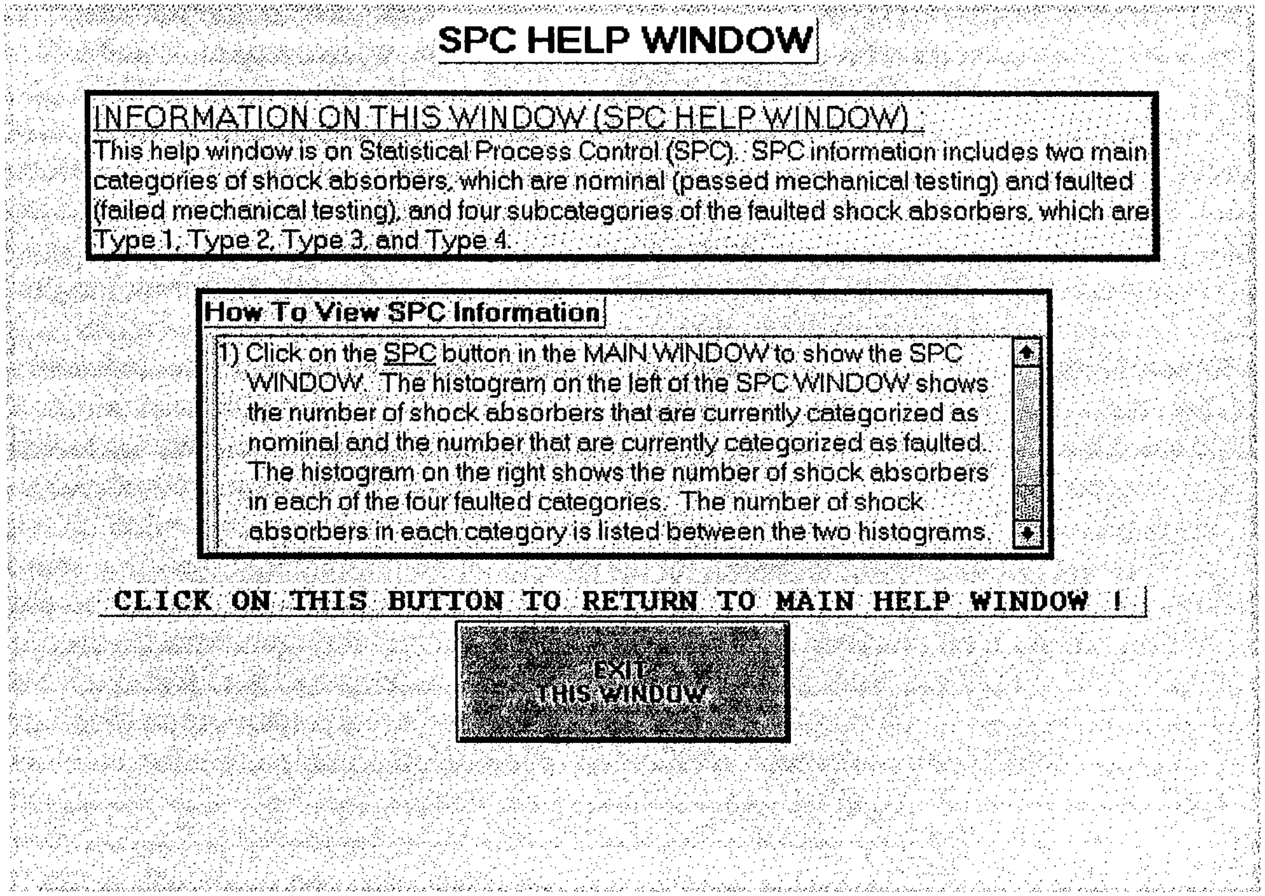
THE TEST STAND OPERATION HELP WINDOW



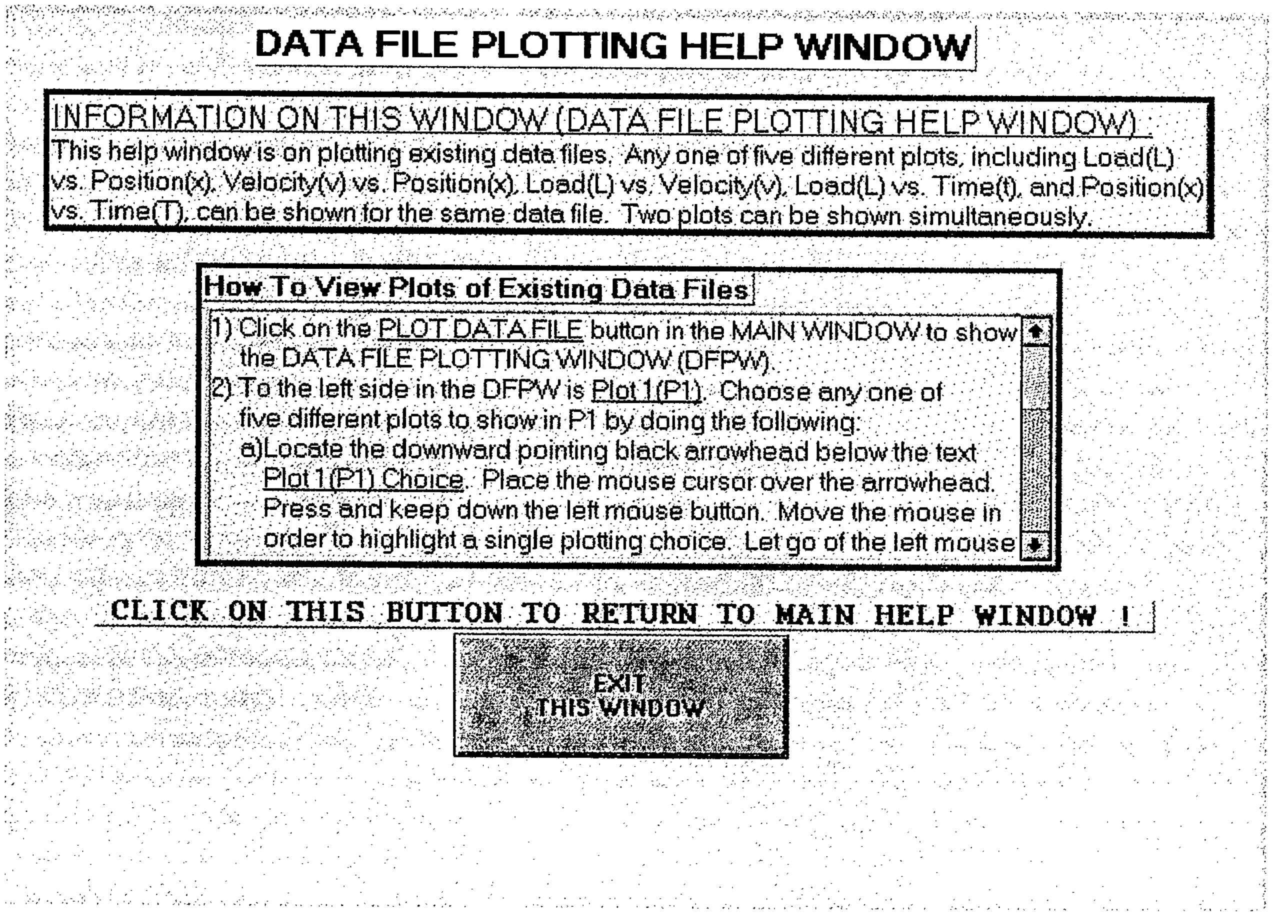
THE SHOCK ABSORBER(SA) TESTING HELP WINDOW



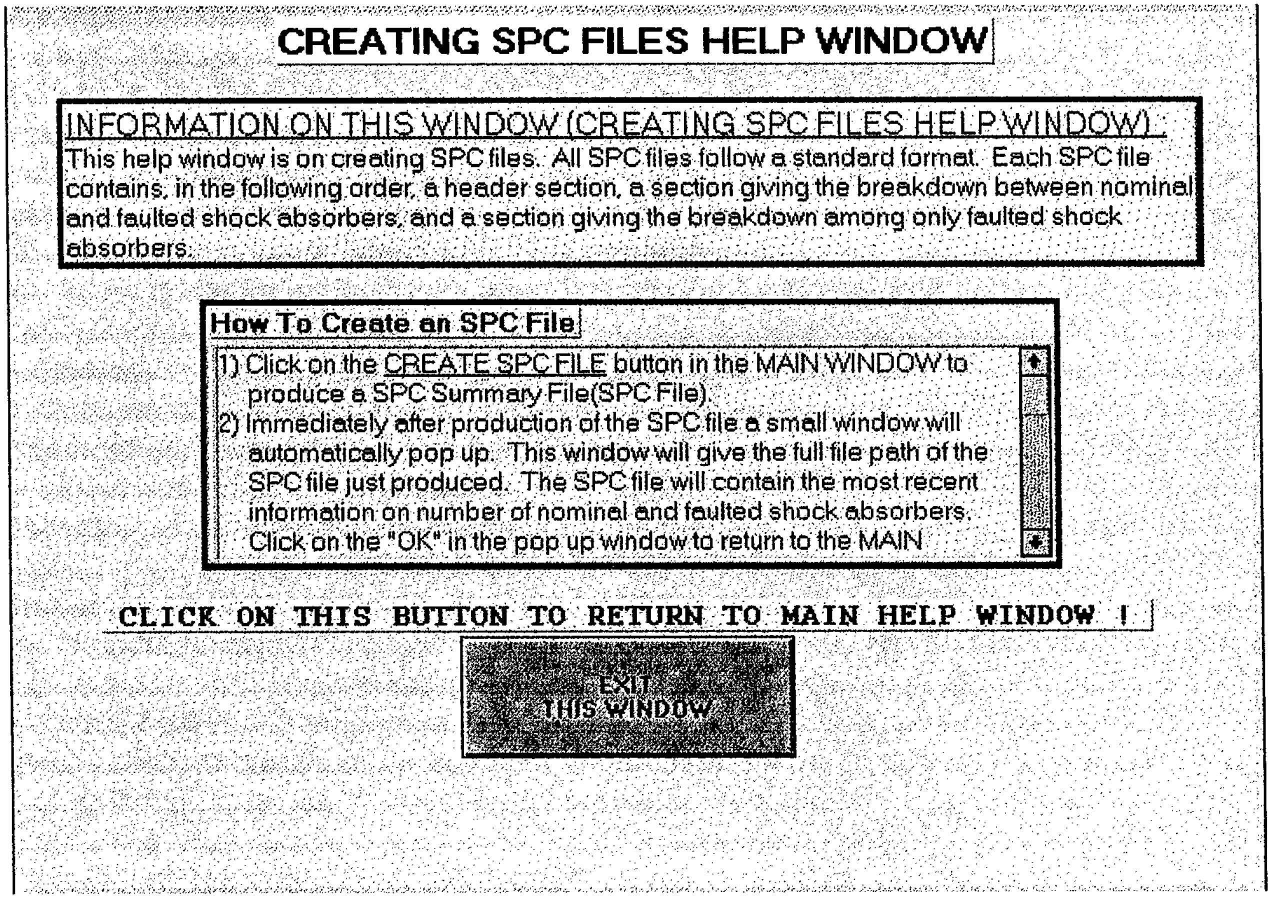
THE SPC HELP WINDOW



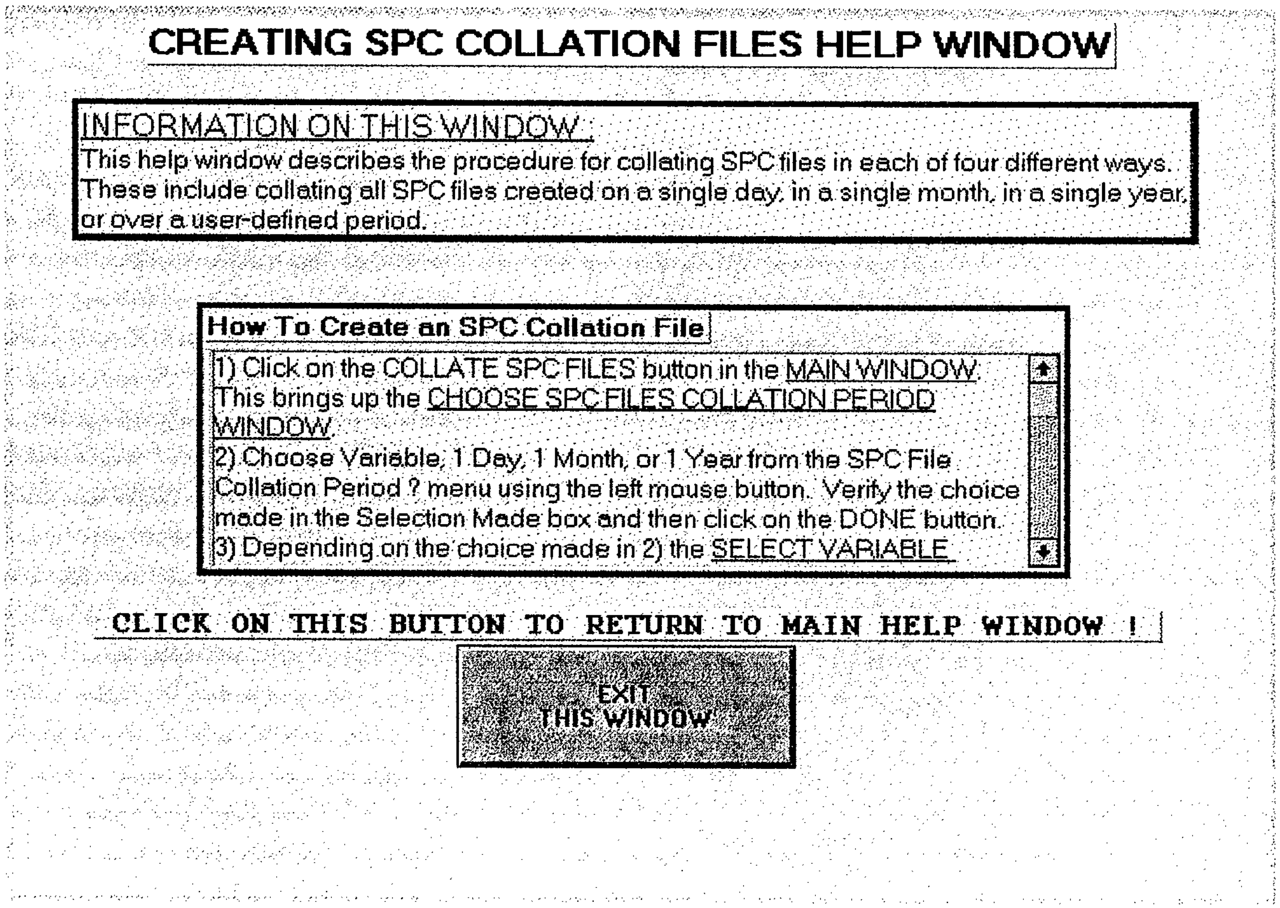
THE DATA FILE PLOTTING HELP WINDOW



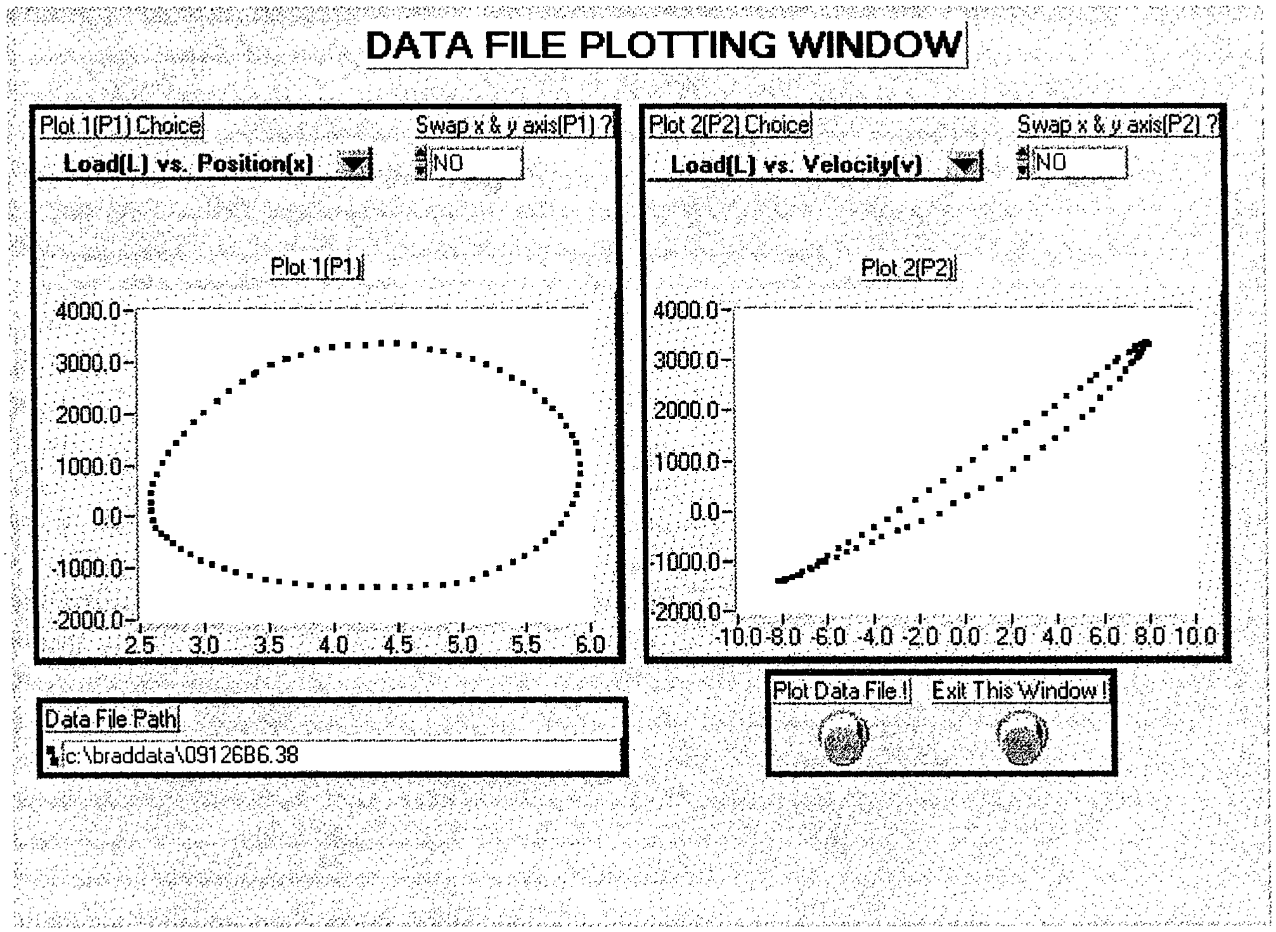
THE CREATING SPC FILES HELP WINDOW



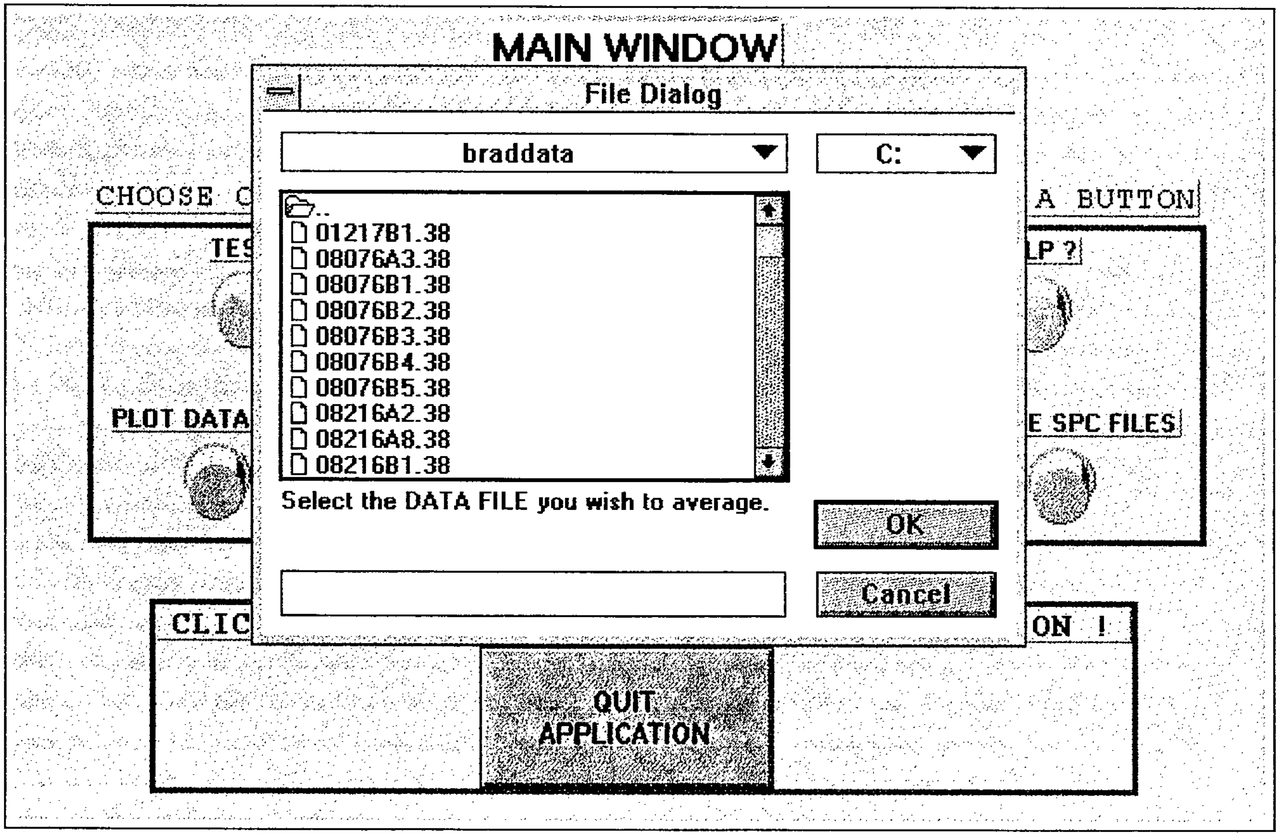
THE CREATING SPC COLLATION FILES HELP WINDOW



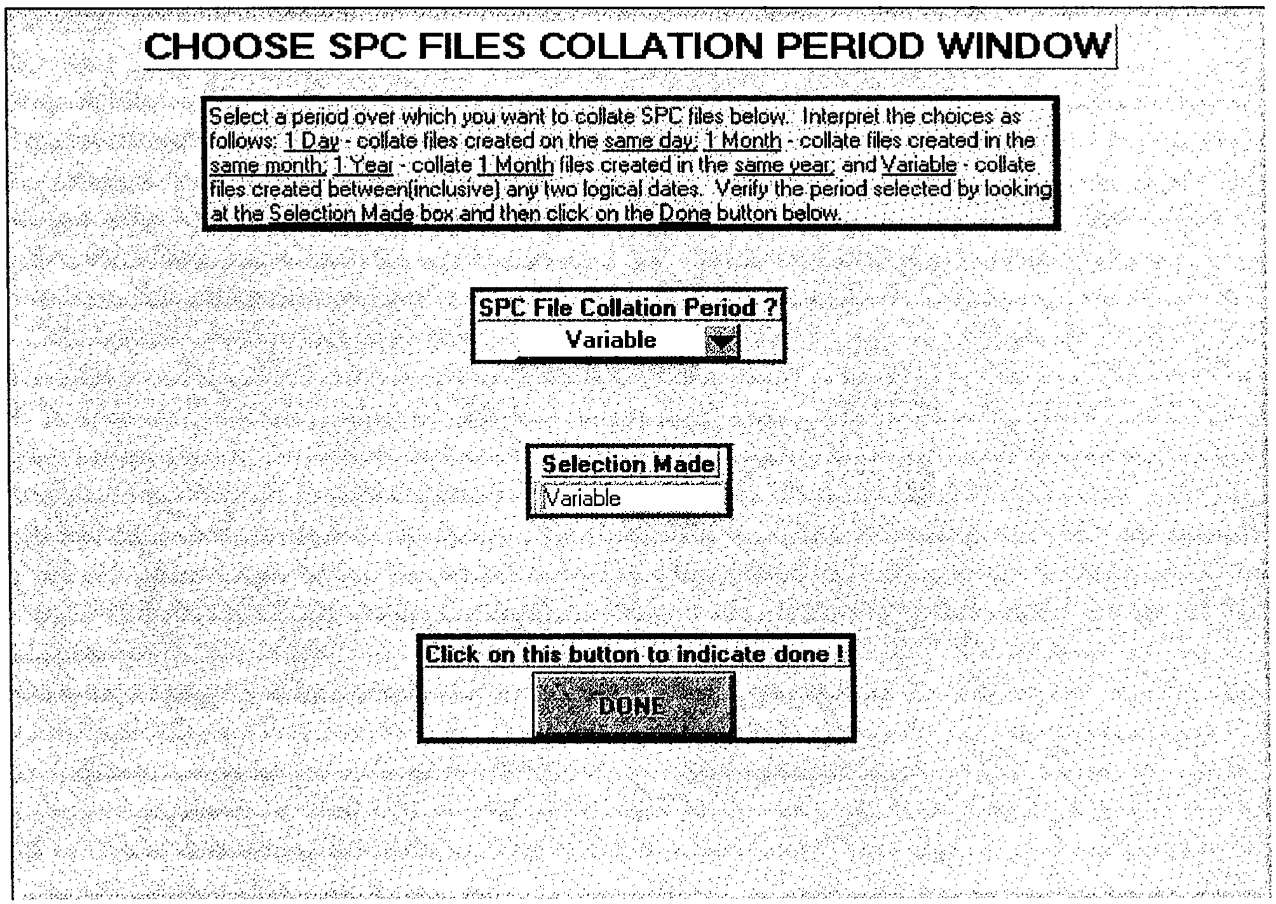
THE DATA FILE PLOTTING WINDOW



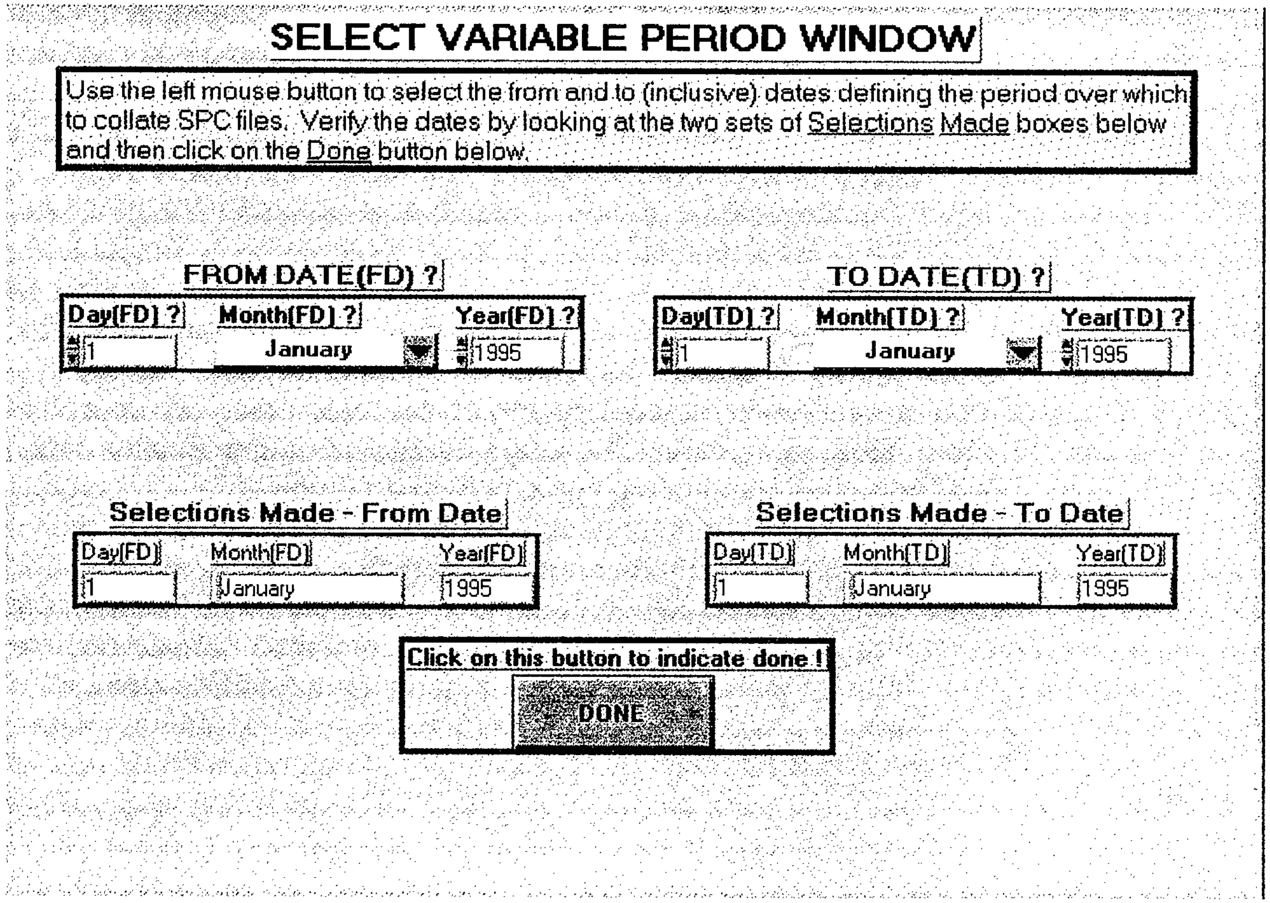
THE AVERAGE DATA FILE POP-UP WINDOW



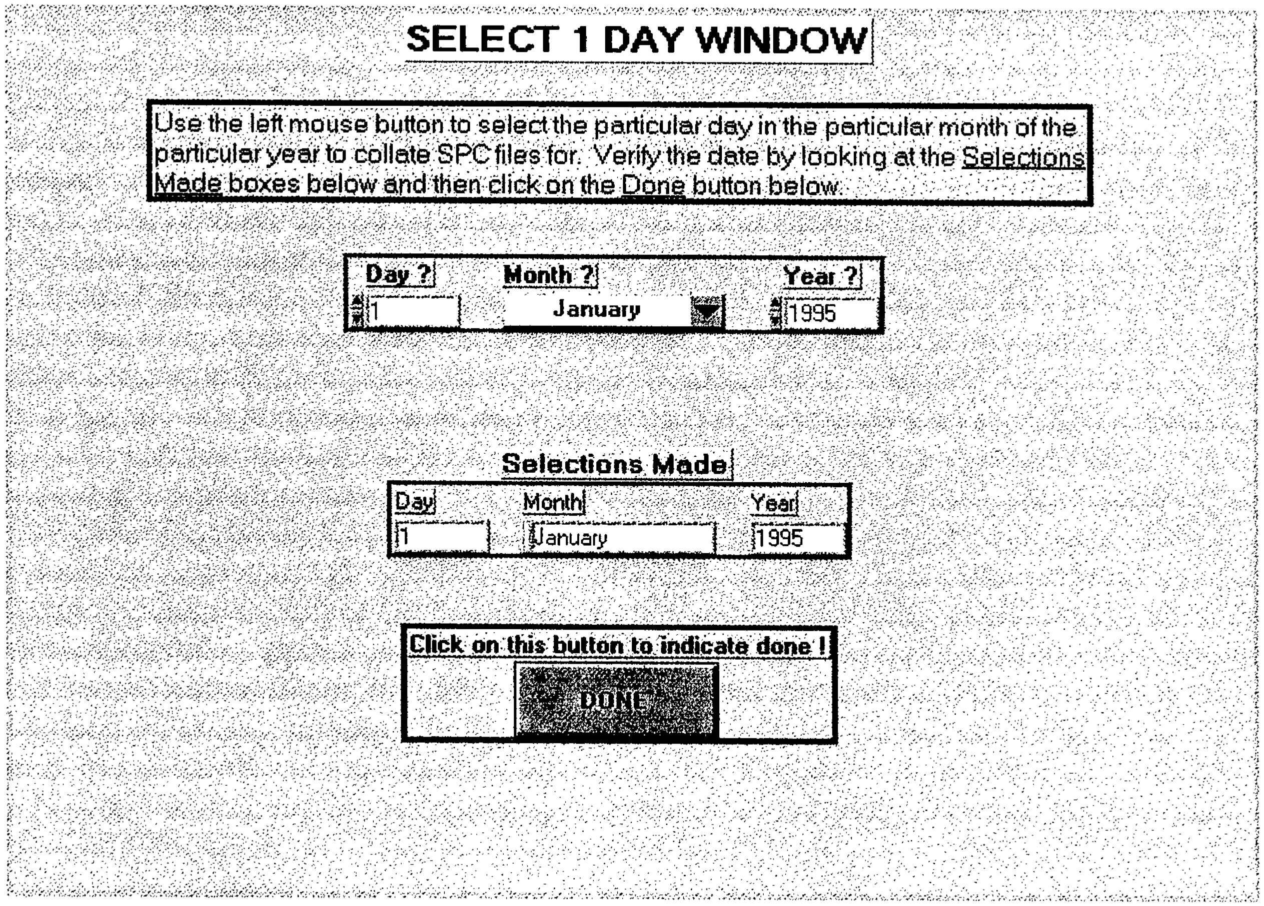
THE CHOOSE SPC FILES COLLATION PERIOD WINDOW



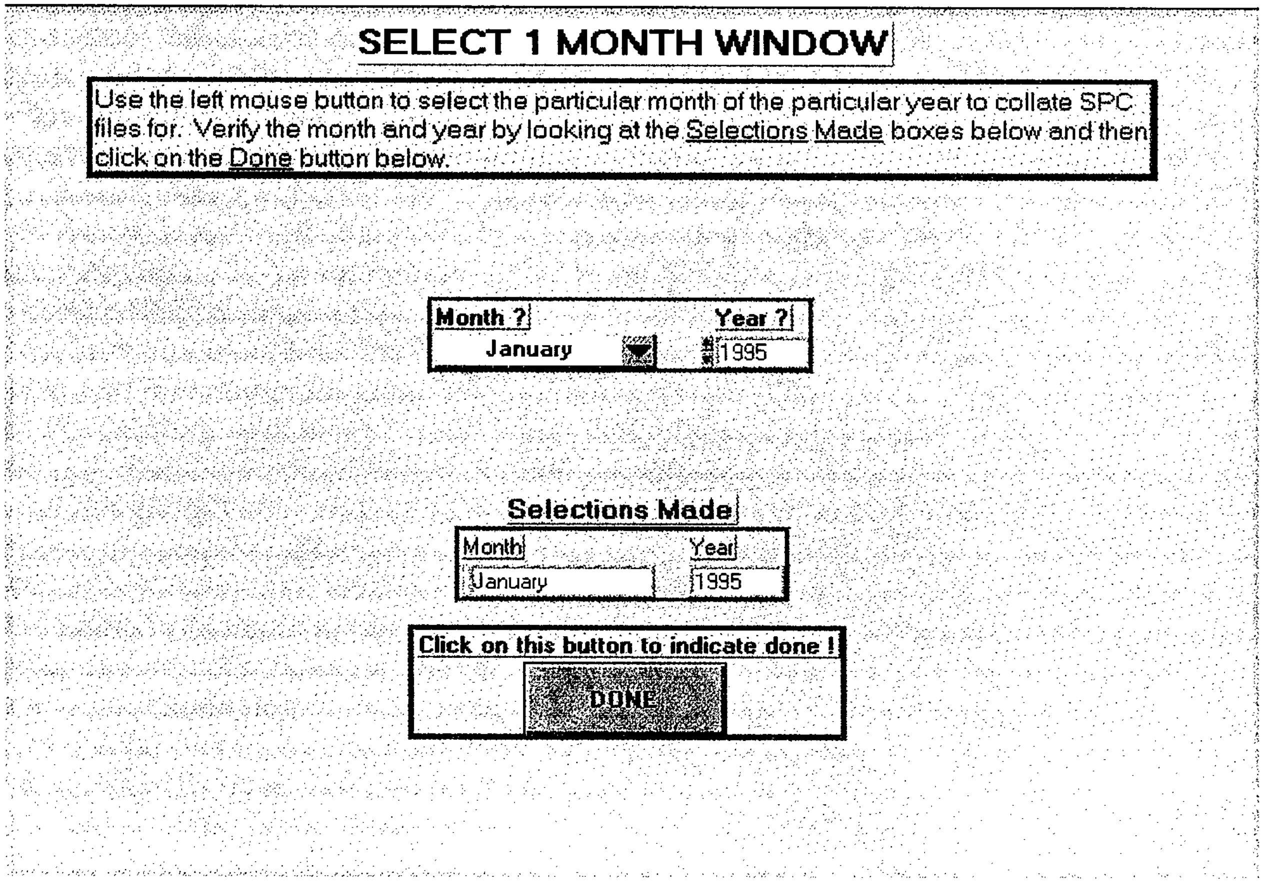
THE SELECT VARIABLE PERIOD WINDOW



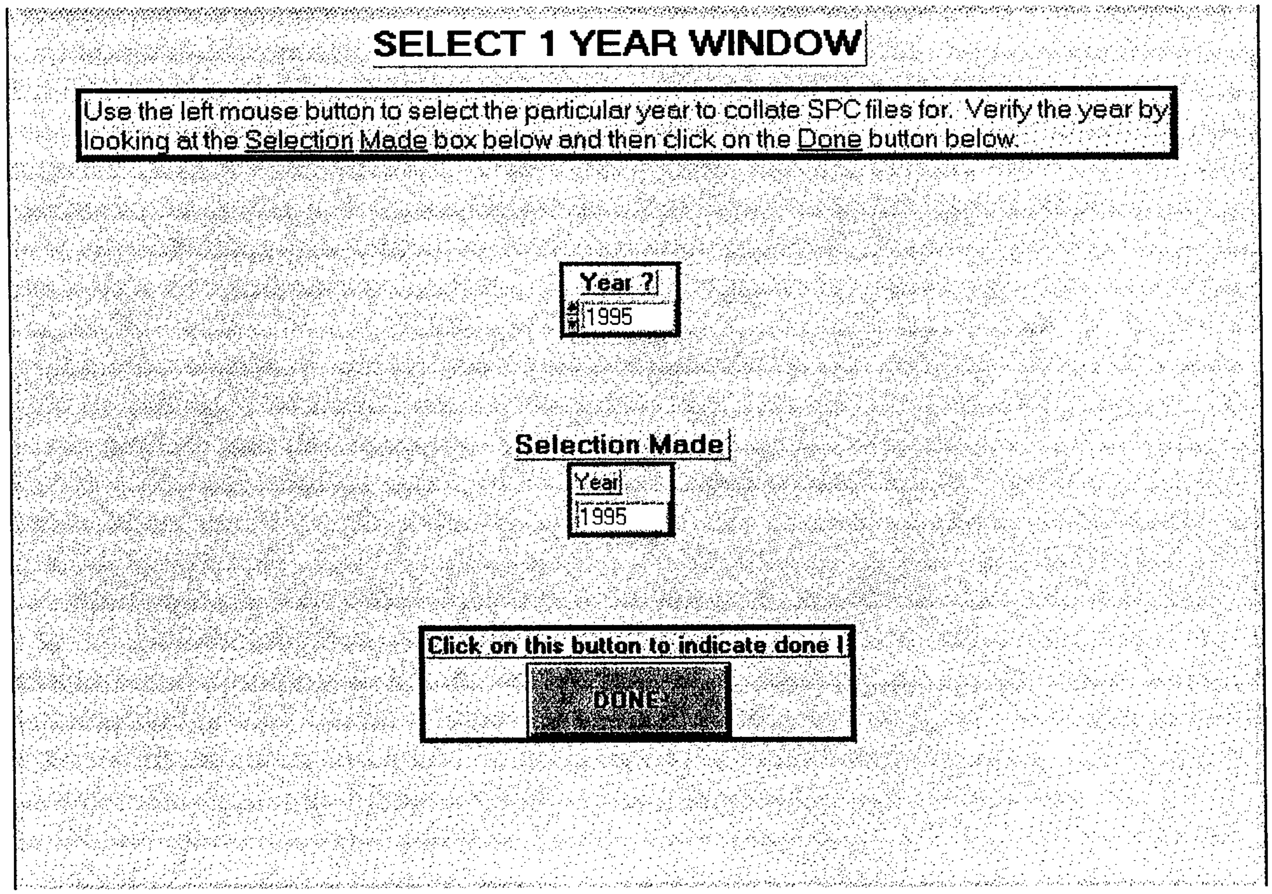
THE SELECT 1 DAY WINDOW



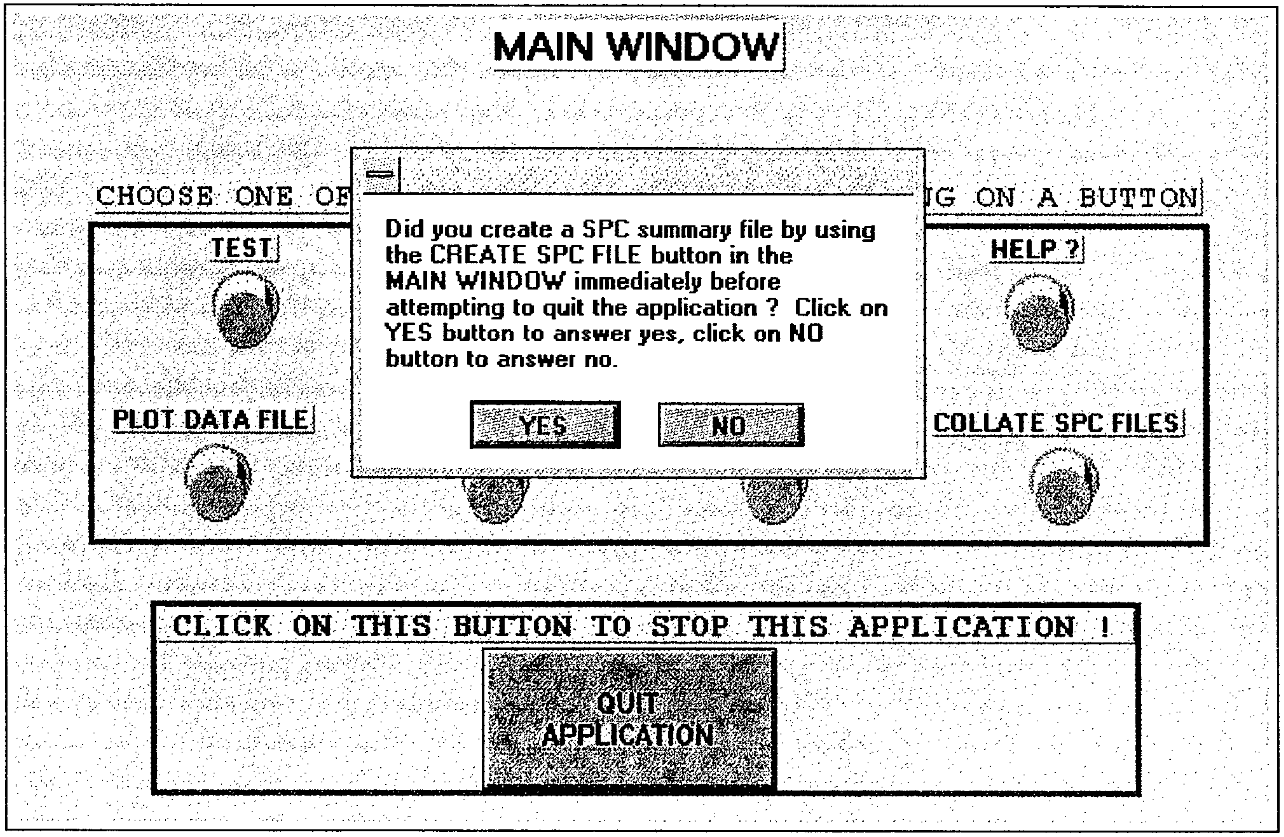
THE SELECT 1 MONTH WINDOW



THE SELECT 1 YEAR WINDOW



THE SPC POP-UP EXIT WINDOW



Appendix B:

Load Values

INTENTIONALLY LEFT BLANK.

Shock Absorber	ML(C) (lb)	ML(R) (lb)	DL(C) (lb)	DL(R) (lb)
08076B1	4,072.27	1,584.07	3,052.92	1,181.31
08076B2	3,724.02	1,661.73	2,765.81	1,417.35
08076B3	589.90	219.63	296.18	241.61
08076B4	4,266.68	1,821.03	2,113.51	1,440.19
08076B5	4,208.92	1,828.55	2,302.00	1,480.47
08216B1	3,299.79	1,458.78	1,838.99	676.45
08216B2	3,386.02	1,319.16	1,900.45	630.78
08216B3	1,312.41	489.40	662.64	39.44
08216B4	3,800.34	1,595.17	2,554.16	1,192.75
08216B5	3,712.48	1,584.72	2,242.92	999.47
08216B6	4,111.43	1,542.53	2,741.77	971.23
08216B7	4,154.77	1,745.90	2,825.54	1,203.83
08216B8	4,069.69	1,618.87	2,700.60	960.31
08216B9	4,601.31	1,864.87	3,456.78	1,496.90
08216B10	4,238.15	1,809.19	3,239.38	1,495.59
08216B11	3,997.82	1,612.05	2,616.41	963.51
08216B12	4,013.38	1,751.12	2,758.00	1,200.16
08216B13	3,780.74	1,609.23	2,508.72	1,117.08
08216B14	4,096.91	1,542.53	2,986.09	1,248.02
08236B1	3,973.17	1,635.56	2,690.17	1,147.65
08236B2	4,075.77	1,631.17	2,782.38	1,133.34
08236B3	4,050.39	1,584.48	2,639.43	990.93
08236B4	3,986.68	1,584.85	2,900.84	1,189.36
08236B5	4,125.01	1,807.15	2,833.04	1,351.95
08236B6	4,127.13	1,686.16	2,915.53	1,157.27
08236B7	3,834.70	1,647.62	2,438.39	976.05

INTENTIONALLY LEFT BLANK.

Appendix C

M(=Met) / F(=Failed) Values

INTENTIONALLY LEFT BLANK.

Shock Absorber	ML(C)	ML(R)	DL(C)	DL(R)
08076B1	M	F	M	M
08076B2	M	F	M	M
08076B3	F	F	F	F
08076B4	M	M	M	M
08076B5	M	M	M	M
08216B1	M	F	M	F
08216B2	M	F	M	F
08216B3	F	F	F	F
08216B4	M	F	M	M
08216B5	M	F	M	M
08216B6	M	F	M	M
08216B7	M	M	M	M
08216B8	M	F	M	M
08216B9	M	M	M	M
08216B10	M	M	M	M
08216B11	M	F	M	M
08216B12	M	M	M	M
08216B13	M	F	M	M
08216B14	M	F	M	M
08236B1	M	F	M	M
08236B2	M	F	M	M
08236B3	M	F	M	M
08236B4	M	F	M	M
08236B5	M	M	M	M
08236B6	M	M	M	M
08236B7	M	F	M	M

Shock Absorber	ML(C)	ML(R)	DL(C)	DL(R)
08236B8	M	F	M	M
08236B9	M	F	M	M
08236B10	M	F	M	M
08236B11	M	F	M	M
08236B12	M	F	M	M
09126B1	M	F	M	M
09126B2	M	M	M	M
09126B3	M	F	F	M
09126B4	M	F	M	M
09126B5	M	F	M	M
09126B6	M	F	M	F
09126B7	M	F	M	M
09126B8	M	M	M	M
09126B9	M	F	M	F
09166B1	M	F	M	M
09166B2	M	F	M	F
09166B3	Invalid Test - Temperature Out of Range			
09166B4	M	F	M	F
09176B1	M	F	M	M
09176B2	Invalid Test - Temperature Out of Range			
09176B3	M	M	M	M
09186B1	M	F	M	F
09186B2	M	F	M	M
09186B3	M	F	M	M
09186B4	M	F	M	M
09186B5	M	F	M	M

Shock Absorber	ML(C)	ML(R)	DL(C)	DL(R)
09186B6	M	F	M	M
09186B7	M	F	M	M
09186B8	M	M	M	M
09186B9	M	F	M	M
09186B10	M	F	M	M

INTENTIONALLY LEFT BLANK.

Appendix D:

Faulted Classification Results

INTENTIONALLY LEFT BLANK.

Shock Absorber	Type (1, 2, 3, or 4)
08076B1	1
08076B2	4
08076B3	2
08216B1	1
08216B2	4
08216B3	1
08216B4	1
08216B5	1
08216B6	1
08216B8	2
08216B11	2
08216B13	1
08216B14	1
08236B1	1
08236B2	4
08236B3	1
08236B4	2
08236B7	1
08236B8	2
08236B9	1
08236B10	2
08236B11	1
08236B12	1
09126B1	1
09126B3	1
09126B4	2

Shock Absorber	Type (1, 2, 3, or 4)
09126B5	2
09126B6	2
09126B7	1
09126B9	1
09166B1	1
09166B2	2
09166B4	2
09176B1	1
09186B1	1
09186B2	1
09186B3	1
09186B4	1
09186B5	1
09186B6	1
09186B7	1
09186B9	2
09186B10	1

NO. OF COPIES	ORGANIZATION
2	DEFENSE TECHNICAL INFORMATION CENTER DTIC DDA 8725 JOHN J KINGMAN RD STE 0944 FT BELVOIR VA 22060-6218
1	HQDA DAMO FDQ DENNIS SCHMIDT 400 ARMY PENTAGON WASHINGTON DC 20310-0460
1	DPTY ASSIST SCY FOR R&T SARD TT F MILTON RM 3EA79 THE PENTAGON WASHINGTON DC 20310-0103
1	OSD OUSD(A&T)/ODDDR&E(R) J LUPO THE PENTAGON WASHINGTON DC 20301-7100
1	CECOM SP & TRRSTRL COMMCTN DIV AMSEL RD ST MC M H SOICHER FT MONMOUTH NJ 07703-5203
1	PRIN DPTY FOR TCHNLGY HQ US ARMY MATCOM AMCDCG T M FISETTE 5001 EISENHOWER AVE ALEXANDRIA VA 22333-0001
1	PRIN DPTY FOR ACQUSTN HQS US ARMY MATCOM AMCDCG A D ADAMS 5001 EISENHOWER AVE ALEXANDRIA VA 22333-0001
1	DPTY CG FOR RDE HQS US ARMY MATCOM AMCRD BG BEAUCHAMP 5001 EISENHOWER AVE ALEXANDRIA VA 22333-0001

NO. OF COPIES	ORGANIZATION
1	INST FOR ADVNCD TCHNLGY THE UNIV OF TEXAS AT AUSTIN PO BOX 202797 AUSTIN TX 78720-2797
1	USAASA MOAS AI W PARRON 9325 GUNSTON RD STE N319 FT BELVOIR VA 22060-5582
1	CECOM PM GPS COL S YOUNG FT MONMOUTH NJ 07703
1	GPS JOINT PROG OFC DIR COL J CLAY 2435 VELA WAY STE 1613 LOS ANGELES AFB CA 90245-5500
1	ELECTRONIC SYS DIV DIR CECOM RDEC J NIEMELA FT MONMOUTH NJ 07703
3	DARPA L STOTTS J PENNELLA B KASPAR 3701 N FAIRFAX DR ARLINGTON VA 22203-1714
1	USAF SMC/CED DMA/JPO M ISON 2435 VELA WAY STE 1613 LOS ANGELES AFB CA 90245-5500
1	US MILITARY ACADEMY MATH SCI CTR OF EXCELLENCE DEPT OF MATHEMATICAL SCI MDN A MAJ DON ENGEN THAYER HALL WEST POINT NY 10996-1786
1	DIRECTOR US ARMY RESEARCH LAB AMSRL CS AL TP 2800 POWDER MILL RD ADELPHI MD 20783-1145

NO. OF COPIES	ORGANIZATION
1	DIRECTOR US ARMY RESEARCH LAB AMSRL CS AL TA 2800 POWDER MILL RD ADELPHI MD 20783-1145
3	DIRECTOR US ARMY RESEARCH LAB AMSRL CI LL 2800 POWDER MILL RD ADELPHI MD 20783-1145
	ABERDEEN PROVING GROUND
4	DIR USARL AMSRL CI LP (305)

NO. OF COPIES	ORGANIZATION
5	COMMANDER RED RIVER ARMY DEPOT SIORR OE ERIC OLSEN BLDG 228 TEXARKANA TX 75507-5000
1	DIR FOR COMPUTATIONAL CHEMISTRY & MATERIALS AMSRL PET MARGARET HURLEY 939 I BEARDS HILL RD STE 193 ABERDEEN MD 21001
1	BOSTON UNIVERSITY COGNITIVE SCIENCE DEPT GERARD RINKUS BOSTON MA 02215
	ABERDEEN PROVING GROUND
6	DIR USARL AMSRL WM MD PATRICK SINCEBAUGH (3 CP) WILLIAM GREEN (3 CP)

INTENTIONALLY LEFT BLANK.

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	February 1998	Final, April 1994 - April 1996

4. TITLE AND SUBTITLE
A Graphical User Interface (GUI) for Automated Classification of Bradley Fighting Vehicle Shock Absorbers

5. FUNDING NUMBERS
783941

6. AUTHOR(S)
Patrick Sincebaugh, William Green, and Gerard Rinkus*

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Research Laboratory
ATTN: AMSRL-WM-MD
Aberdeen Proving Ground, MD 21005-5069

8. PERFORMING ORGANIZATION REPORT NUMBER
ARL-TR-1621

9. SPONSORING/MONITORING AGENCY NAMES(S) AND ADDRESS(ES)

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
*Boston University, Cognitive Science Department, Boston, MA 02215

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
In this report we describe a diagnostic system that is being utilized to evaluate the condition of armored vehicle shock absorbers. We begin by providing the motivation behind the development of the smart shock absorber test stand (SSATS). We then describe the theory required to evaluate the condition of shock absorbers. This theoretical discussion leads to a description of what real life data are acquired during a shock absorber test, and how it can be analyzed to determine the condition of a shock absorber. We then explain the design and capabilities of the SSATS graphical user interface (GUI), which includes the integration of a neural network classification scheme. We finish by discussing recent results of utilizing the system to test and evaluate Bradley armored vehicle shock absorbers.

14. SUBJECT TERMS
graphical user interface (GUI), neural network automated classification shock absorbers, Bradley SSATS, real time

15. NUMBER OF PAGES
65

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18 298-102

INTENTIONALLY LEFT BLANK.

USER EVALUATION SHEET/CHANGE OF ADDRESS

This Laboratory undertakes a continuing effort to improve the quality of the reports it publishes. Your comments/answers to the items/questions below will aid us in our efforts.

1. ARL Report Number/Author ARL-TR-1621 (Sincebaugh) Date of Report February 1998

2. Date Report Received ____________________

3. Does this report satisfy a need? (Comment on purpose, related project, or other area of interest for which the report will be used.) ____________________

4. Specifically, how is the report being used? (Information source, design data, procedure, source of ideas, etc.) ____________________

5. Has the information in this report led to any quantitative savings as far as man-hours or dollars saved, operating costs avoided, or efficiencies achieved, etc? If so, please elaborate. ____________________

6. General Comments. What do you think should be changed to improve future reports? (Indicate changes to organization, technical content, format, etc.) ____________________

CURRENT ADDRESS

Organization

Name E-mail Name

Street or P.O. Box No.

City, State, Zip Code

7. If indicating a Change of Address or Address Correction, please provide the Current or Correct address above and the Old or Incorrect address below.

OLD ADDRESS

Organization

Name

Street or P.O. Box No.

City, State, Zip Code

(Remove this sheet, fold as indicated, tape closed, and mail.)
(DO NOT STAPLE)

DEPARTMENT OF THE ARMY

OFFICIAL BUSINESS

NO POSTAGE
NECESSARY
IF MAILED
IN THE
UNITED STATES

BUSINESS REPLY MAIL
FIRST CLASS PERMIT NO 0001,APG,MD

POSTAGE WILL BE PAID BY ADDRESSEE

DIRECTOR
US ARMY RESEARCH LABORATORY
ATTN AMSRL WM MD
ABERDEEN PROVING GROUND MD 21005-5066